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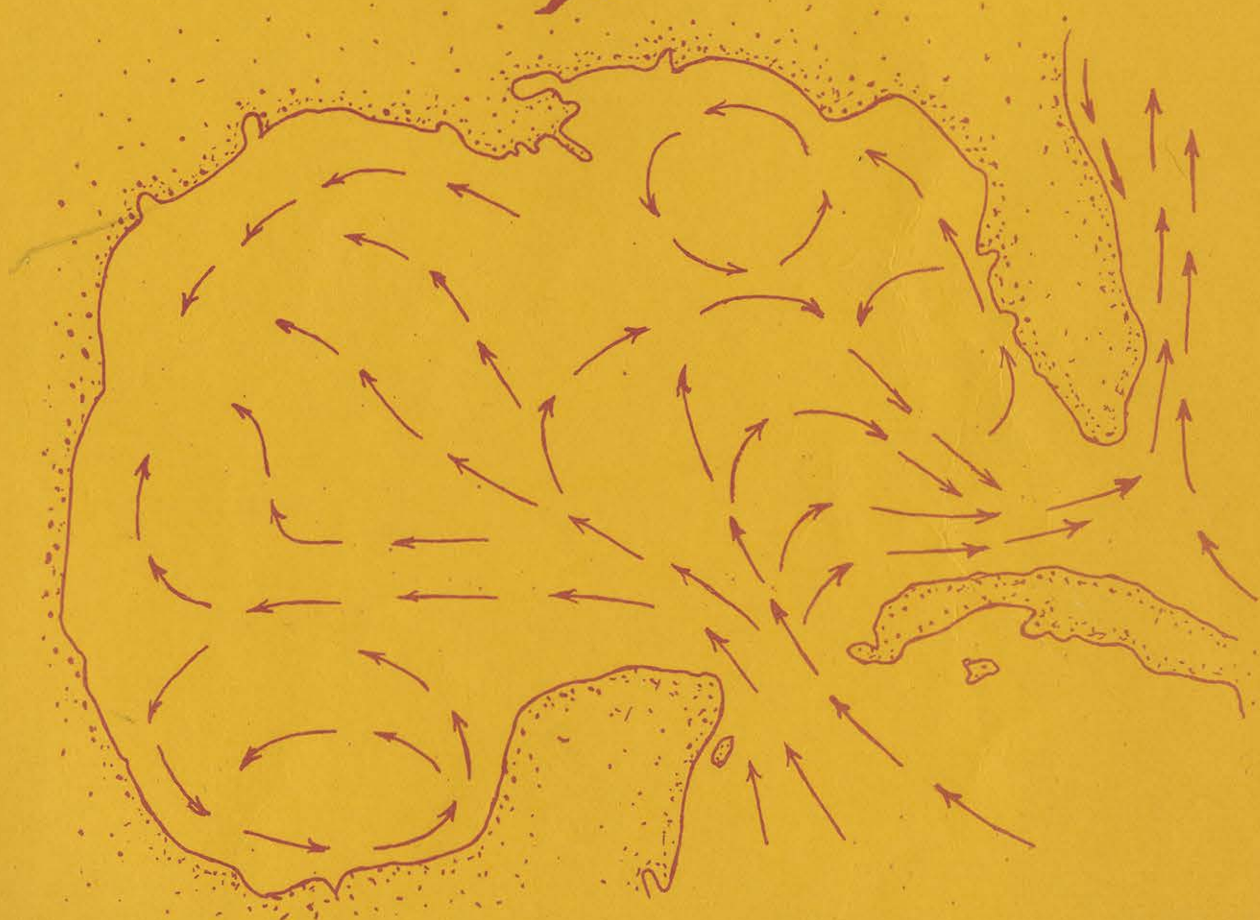
Hydrography

JOURNAL of MARINE SCIENCE



MARINE SCIENCES INSTITUTE

Bayou La Batre

Alabama

Volume 1 1969 Number 1

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Papers submitted to the editor for publication in the Journal of Marine Science should be relevant to the marine milieu of the Gulf of Mexico or adjacent waters but may have wider scope. Subject matter may include, but is not limited to, marine biology, fisheries, marine geology, oceanography, sanitary or marine engineering, fishery technology, and any health-related aspect of marine science. They may be either original research or reviews in English, Spanish, or French. Articles are accepted without limitation as to origin, but must not have been published elsewhere or copyrighted. Opinions expressed by authors do not necessarily reflect those of the Institute.

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EDITORIAL FOREWORD

Seldom does a journal essay its maiden flight without editorial comment; we shall not risk breaking with tradition.

Many ask why the sudden interest in the sea--she has always been with us. But has she? Man has long sailed her surface, becalmed by doldrums, tossed about by lusty gales, awed by her vastness. In all the many centuries that passed man did not plumb her depths, could not delve into her secrets.

The sea is the last great frontier on earth--we know far less of the bottom of the sea than of the surface of the moon. However, as man systematically plundered the terrestrial domain he began to dimly wonder about the much vaster area he had neglected. How vast are the treasures he seeks? Out of 27 phyla of animals, all are represented in the sea, 12 are exclusively marine. Vast reserves of minerals and fossil fuel lie on and under the bottom. The tides and winds themselves are a vast source of almost untapped energy. These treasures must be wrested from hostile environment, long alien to man. Only recently has advancing technology permitted man brief glimpses of what lies in the Stygian depths beyond the continental shelves.

Where sea meets land, man, with his chemical and industrial wastes, his eagerness to fill productive wetlands for factory sites and housing developments, his flaunting of natural laws, has jeopardized the most valuable of the sea's resources--capacity to produce the animal proteins now being feverishly sought to allay the impact of burgeoning populations.

Many skilled people are needed to guide the rational exploitation of the seas. Many desire to share this task; few have the unique opportunity.

The Marine Sciences Institute was founded in 1966 to provide this opportunity to more scientists and students. Despite heavy involvement with the land, the State of Alabama has a long and distinguished marine history. On the verge of man's return to the sea we should pause to consider not only the opportunities, but the need for trained personnel. We have qualified people throughout the area who we feel sure welcome the challenge, and the Marine Sciences Institute welcomes their involvement. Only by enlisting the talents of many scientists can we hope to conquer the seas.

STUDIES ON THE CROAKER, *MICROPOGON UNDULATUS* LINNAEUS, AND THE SPOT, *LEIOSTOMUS XANTHURUS* LACEPEDE, IN MOBILE BAY, ALABAMA[1]

Walter R. Nelson[2]
University of Alabama

ABSTRACT

Thirty-two otter trawl stations were sampled at least bi-monthly in Mobile Bay from May, 1963 through April, 1964. Two hundred and sixty-four samples, with concomitant hydrographic data were collected. General salinity and temperature conditions within the bay are discussed. Data on the spawning period, spawning location, age, growth, movement, abundance, seasonal distribution and relation to salinity, temperature, and depth of the croaker, *Micropogon undulatus* Linnaeus, and the spot, *Leiostomus xanthurus* Lacepede in Mobile Bay are presented and discussed. Offshore data on the croaker and spot allow the study of three age classes from spawning until the two species are in their third year of age. The estuary is utilized by both species until they reach maturity, at which time they go offshore to spawn.

INTRODUCTION

In a paper on the commercial bottomfish industry of the northern Gulf of Mexico, Roithmayr (1965a) stressed the value of the croaker, *Micropogon undulatus*, and the spot, *Leiostomus xanthurus*, in the northern Gulf of Mexico. This fishery involves the taking, by otter trawl, of small, benthic fishes in nearshore and offshore areas along the Gulf coast from Point au Fer, Louisiana to Perdido Bay, Florida. These fishes, processed as pet-food, are a valuable resource. Also as food fish and sports fish. - G. G.

[1]The data were gathered through a University of Alabama contract with the Seafoods Division, Alabama Department of Conservation.

[2]Present address: Exploratory Fishing and Gear Research Base, U. S. Bureau of Commercial Fisheries, Pascagoula, Mississippi, 39567.

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In 1962, 48,000 tons of bottomfish, worth 1.6 million-dollars to the fishing fleet, were utilized in a 14.9-million-dollar pack by pet-food canners in Mississippi. A majority of the industry's effort is expended east of the Mississippi River Delta, and about one-half of the total effort is expended within a fifty-mile radius of the mouth of Mobile Bay. The croaker comprises 55.5 percent, and the spot 13 percent of the total industrial catch east of the Mississippi River.

In May, 1963 an estuarine survey of major Alabama inshore waters was initiated to determine the size distribution and relative density of demersal species in relation to varying ecological factors. Juvenile croaker and spot were the two most abundant benthic fishes present in Mobile Bay during that survey. The Mobile Bay area thus appears to be of major importance to the multi-million dollar pet-food industry.

The life histories of the croaker and spot have been studied in some detail by a number of authors, but work concerning the seasonal distribution; relative density; density and size in relation to depth, temperature, and salinity; and the value of estuaries as nursery grounds for these species is less common. This paper provides some insight into these variables in the Mobile Bay area, which adds to the understanding of the value of estuaries, and of these two species of fishes.

DESCRIPTION OF AREA

Mobile Bay is a large, shallow estuary approximately 27 miles in length in a north to south direction and about 11 miles in average width, with a maximum width between Cedar Point and Bon Secour River, of nearly twenty miles. The overall area, according to Austin (1954) is approximately 300 square miles. The average depth at mean low water is approximately 10 feet, with a depth of 60 feet in a small area at the entrance to the Gulf off Fort Morgan. Most of the bay has a rather uniform depth of 10 to 12 feet. A 42-foot-deep ship channel runs down the mid-western side of the bay for its complete length. Spoil from dredging operations is dumped primarily on the western side of this channel. The spoil bank has effectively divided Mobile Bay into two east-west units below a depth of 4 to 5 feet in the lower bay, and 0 to 3 feet in the upper part of the bay. A small channel is maintained from the ammunition depot at North Deer River to this channel. The Intracoastal Waterway, dredged to a depth of 15 feet, runs east to west through the lower part of Mobile Bay and Bon Secour Bay. Except for these channels, and scattered oyster beds, the bottom topography of Mobile Bay is flat, with few irregularities.

Austin (1954), states that "....the shore lines of the bay are being eroded away due to wave action at a rate of approximately 0.5 feet per year. The resultant sediment is being carried out of the lower bay at a rate to maintain a fairly constant depth. However, there is much evidence that active silting and sedimentation is taking place in the upper reaches of the bay."

Rather extensive grass beds in the shallower upper reaches of the bay, extend down the western shore to a point south of Fowl River, and occur in scattered shallow areas on the eastern shore of the northern bay. Most of the bottom is composed of soft silts and clay, with sand predominating along the shallow shorelines in east and south Mobile Bay.

Drainage from most of Alabama and portions of Georgia and Mississippi enters the bay, through the Mobile, Tensaw, Raft, Appalachee, and Blakely Rivers, which empty into the northern end, with the major share of the water carried by the Mobile and Tensaw (Austin, 1954). These five rivers are distributaries of the Alabama and Tombigbee Rivers, and form a rather extensive delta area north of the Mobile Bay causeway. Since the causeway is predominately fill, with bridges spanning only the major waterways, it must have a rather profound effect on tidal and fresh water interchange in the upper reaches of the bay. Although several small rivers and streams enter Mobile Bay below the causeway, Austin (1954) feels that their contribution is quite small.

Two major passes open into the Gulf of Mexico to the south, although one is indirect. The main outlet, or mouth of the bay, is approximately 2.8 nautical miles in width, Austin (1954), states that it "...handles approximately 3/4 of the total volume which is flushed into or out of Mobile Bay." Pass Aux Herons opens into Mississippi Sound and handles the remaining 1/4 of the tidal volume. The Intracoastal Waterway leading from Bon Secour to Perdido Bay is considered to have a minor role in the tidal interaction.

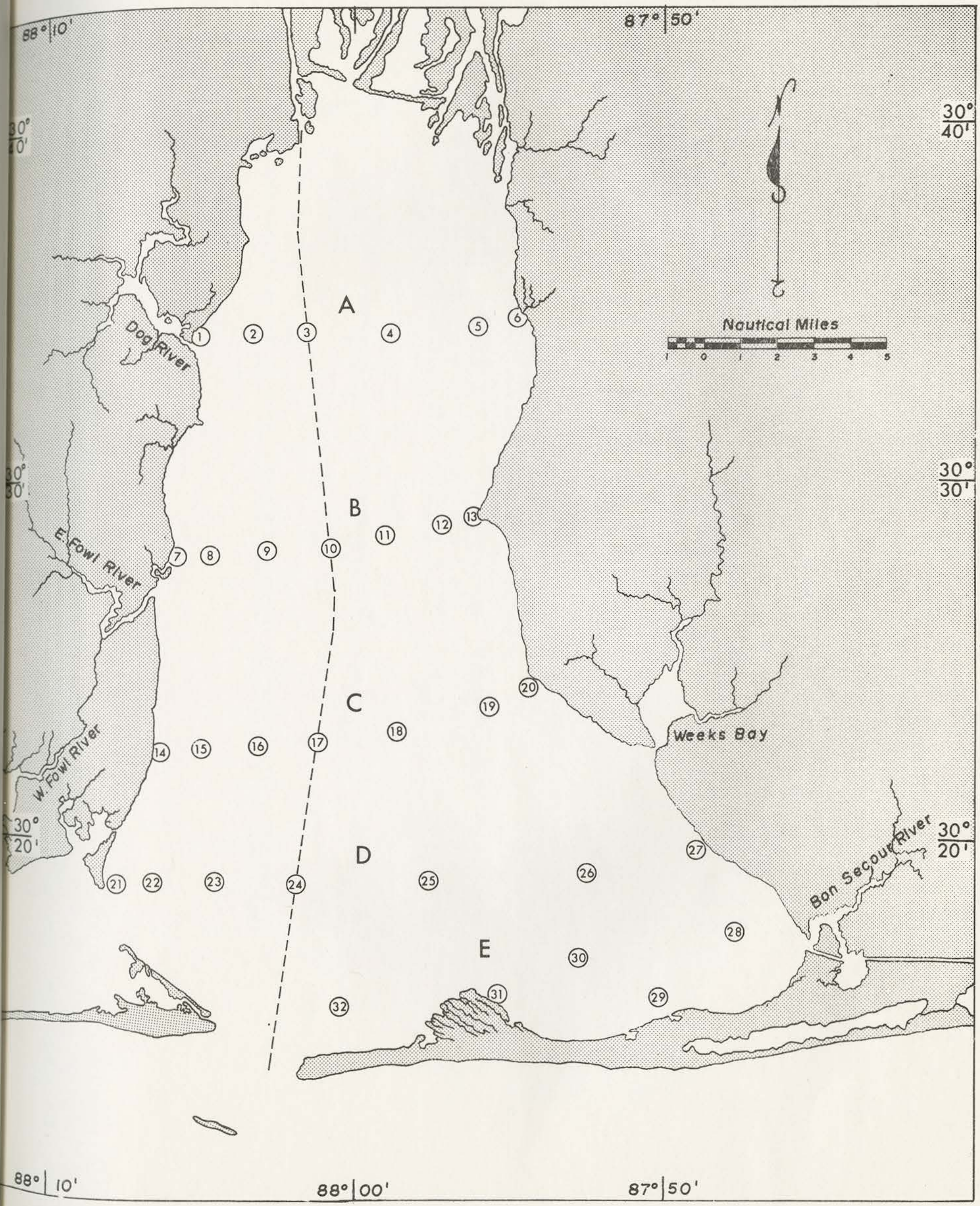
The tidal cycle in Mobile Bay is diurnal, with one high and one low in a twenty-four hour period. During the bi-weekly neap tides, however, two highs or two lows occur within one day. According to R. Merrill McPhearson (personal communication), "....the mean diurnal range in the bayous and inlets along the Alabama coast varies from 1.8-feet to approximately 0.6-feet. The mean range in Mobile Bay varies from 1.5-feet at the head of the bay to 1.2-feet at the entrance." As Mobile Bay is long and fairly wide, the tides are often overcome or accentuated by local winds. Tidal cycles also exhibit seasonal fluctuation with mean low water in the winter varying from 1.0 to 0.5-feet below that of the summer.

Currents in Mobile Bay follow the general pattern of right hand intrusion of tidal flow into a north-south oriented estuary in the northern hemisphere due to Corioli's effect. This counter-clockwise flow is accentuated by a diversion of river flow to and down the western side of the bay. However, the barely submerged spoil bank on the western side of the channel, as well as the "ditch" formed by the channel itself, cause turbulence and diversion, impeding completion of the counter-clockwise circulation pattern. On an ebb tide flow is usually straight towards the mouth of Mobile Bay and the pass to Mississippi Sound. There appears to be a definite two-layer system in effect, in which river water flows seaward over an incoming high density wedge of Gulf water.

DESCRIPTION OF SURVEY

Biological and hydrographic collections were made at thirty-two stations in Mobile Bay along five east-west transects running from upper to lower Mobile Bay referred to as station groups, A, B, C, D, and E, in a north to south direction, (Figure 1). Stations were located nearshore, (less than six feet of depth), in mid-depth areas, and in the 42-foot-deep ship channel. Table 1 lists for each station the depth, latitude, longitude, and bottom type. Sampling frequency is given in Table 2. Monthly sampling was planned, but weather and mechanical difficulties prevented this schedule from being followed in its entirety. At all stations, except for three in transect C during the winter, samples were taken at least bi-monthly (Table 2). Transect A contains six stations, B, C, and D, contain seven stations each, and E contains five stations. Ten stations were in depths of less than six feet, ten stations were in depths of 7-11 feet, 8 stations were in depths of 12-19 feet, and four, stations were in depths of 42-feet in the Mobile ship channel. Bottom type ranged from soft silty clay to hard sand. As shown in Table 1, a variety of bottom types and combinations were sampled. Bottom types were determined by Mr. John J. Ryan of Florida State University using the percentage groupings shown in Figure 2.

FIGURE 1. Otter trawl sampling stations in Mobile Bay.



88° 10'
87° 50'
30° 40'
30° 30'
30° 20'
Nautical Miles
1 0 1 2 3 4 5
A
B
C
D
E
Dog River
E. Fowl River
W. Fowl River
Weeks Bay
Bon Secour River
1 2 3 4 5 6
7 8 9 10 11 12 13
14 15 16 17 18 19 20
21 22 23 24 25 26 27
28 29 30 31 32
88° 00'

Table 1. Mobile Bay station locations, May, 1963 - April, 1964

Group	Station No.	Depth	N. Lat.	W. Long.	Bottom Type
A	1	4	30°34'2"	88°04'7"	soft sand
	2	8	30°34'2"	88°03'7"	soft silty sand
	3	42	30°34'4"	88°01'8"	soft silty clay
	4	12	30°34'7"	87°58'5"	soft sandy silt
	5	8	30°34'7"	87°56'2"	soft sandy silt
	6	4	30°34'7"	87°55'2"	sand
B	7	4	30°27'8"	88°05'8"	sand
	8	9	30°27'9"	88°05'0"	soft silty clay
	9	13	30°28'0"	88°03'4"	hard silty clay
	10	42	30°28'2"	88°01'1"	soft silty clay
	11	12	30°28'5"	87°59'0"	soft silty clay
	12	9	30°28'8"	87°57'3"	hard sand
	13	5	30°29'0"	87°56'4"	hard sand
C	14	4	30°22'2"	88°06'1"	hard sand
	15	9	30°22'3"	88°05'5"	soft silty clay
	16	12	30°22'6"	88°03'8"	soft silty clay
	17	42	30°22'8"	88°01'2"	soft silty clay
	18	13	30°23'3"	87°58'0"	hard silty clay
	19	8	30°24'1"	87°55'2"	sand-silt-clay
	20	4	30°24'4"	87°54'2"	hard sand
D	21	4	30°18'9"	88°07'9"	hard sand
	22	8	30°19'1"	88°06'4"	hard silty clay
	23	13	30°19'2"	88°04'1"	soft silty clay
	24	42	30°19'3"	88°02'7"	soft silty clay
	25	12	30°19'2"	87°57'6"	hard silty clay
	26	10	30°19'6"	87°52'1"	hard silty clay
	27	4	30°19'9"	87°48'6"	hard sand
E	28	8	30°17'6"	87°46'9"	soft silty clay
	29	5	30°16'3"	87°49'4"	soft silty clay
	30	9	30°17'4"	87°53'2"	soft silty clay
	31	4	30°15'5"	87°55'2"	hard sand
	32	19	30°14'9"	88°00'8"	sand-silt-clay

FIGURE 2. Sand-silt-clay percentage groupings used to determine bottom types for Mobile Bay stations presented in Table 1. (Figure provided by Mr. John Ryan, Department of Geology, Florida State University).

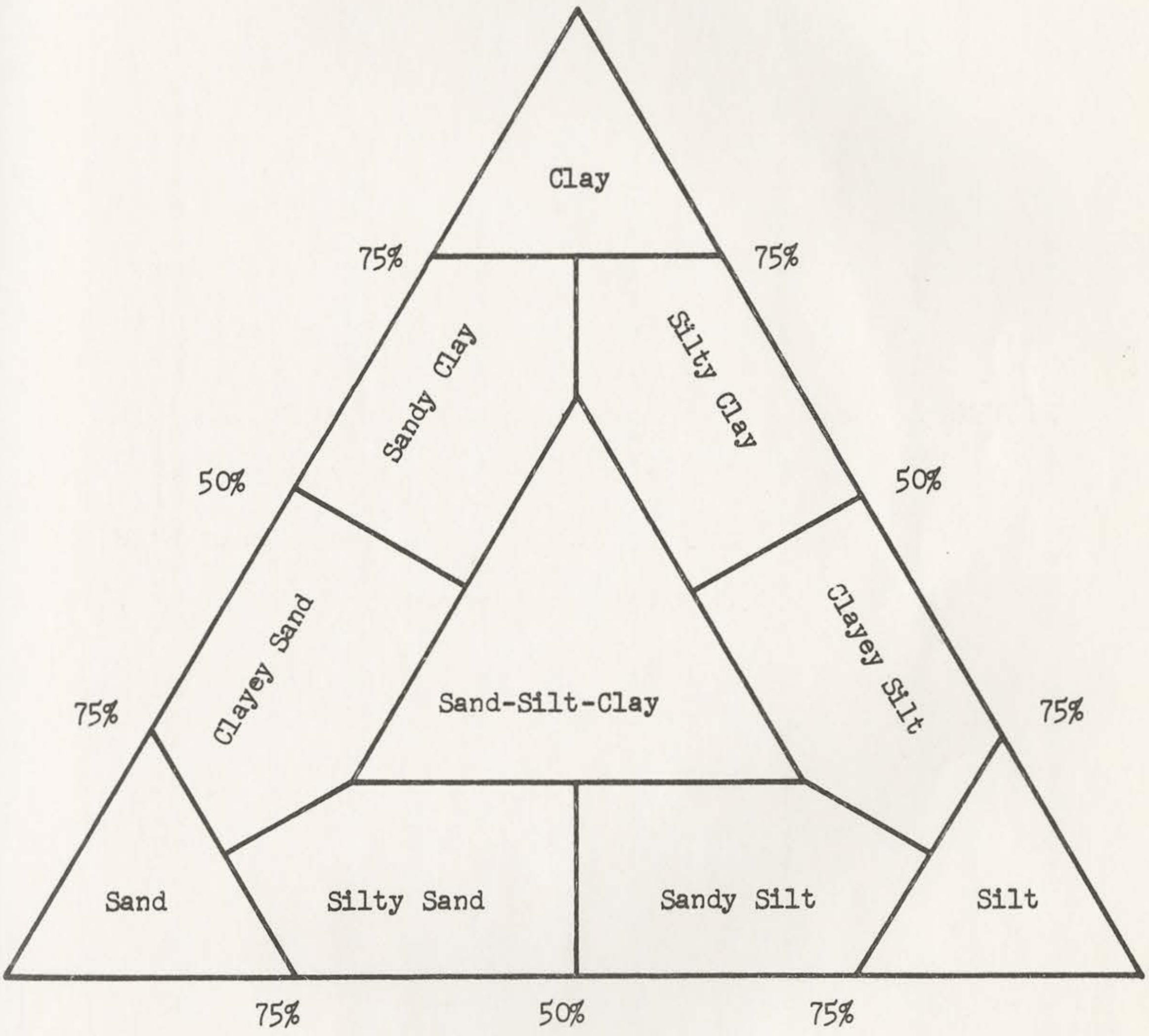

Clay
75%
75%
Sandy Clay
Silty Clay
50%
50%
Clayey Sand
Clayey Silt
Sand-Silt-Clay
75%
75%
Sand
Silty Sand
Sandy Silt
Silt
75%
50%
75%

Table 2. Sampling frequency of survey stations, May, 1963 - April, 1964

Station Group	Station	June	July Aug	Sept[1] Oct	Nov Dec	Jan Feb	Mar Apr	Total
A	1	2	1	1	2	1	1	8
	2	2	1	1	2	1	1	8
	3	2	1	1	2	1	1	8
	4	2	1	1	2	1	1	8
	5	2	1	1	2	1	1	8
	6	2	1	1	2	1	1	8
B	7	2	1	1	1	1	1	7
	8	2	1	1	1	2	1	8
	9	2	1	1	1	2	1	8
	10	2	1	1	1	2	1	8
	11	2	1	1	1	2	1	8
	12	2	1	1	1	2	1	8
	13	2	1	1	1	2	1	8
C	14	2	1	1	1	0	2	7
	15	2	1	1	1	0	2	7
	16	2	1	1	1	0	2	7
	17	2	1	1	1	1	2	8
	18	2	1	1	1	1	2	8
	19	2	1	1	1	1	2	8
	20	2	1	1	1	1	2	8
D	21	2	2	1	1	1	2	9
	22	2	2	1	1	1	2	9
	23	2	2	1	1	1	2	9
	24	2	2	1	1	1	2	9
	25	2	2	1	1	1	2	9
	26	2	2	1	1	1	2	9
	27	2	2	1	1	1	2	9
E	28	2	2	1	1	1	2	9
	29	2	2	1	1	1	2	9
	30	2	2	1	1	1	2	9
	31	2	2	1	1	1	2	9
	32	2	2	1	1	1	2	9
TOTAL		64	44	32	38	35	51	264

[1] No samples taken in September

MATERIALS AND METHODS

Hydrographic Sampling: Temperature, depth and salinity were taken at all stations. Depth was measured with a lead line to the nearest foot, with allowances for tide levels. During the early portion of the survey, temperatures and salinities were obtained from water samples taken with a Nansen bottle. Temperature was determined to the nearest one-half degree Centigrade. Salinity was determined by silver nitrate-potassium dichromate titration recorded to the nearest one-tenth of a part per thousand. During the latter part of the survey, a portable induction salinometer (Industrial Instruments Model RS-5), greatly facilitated hydrographic sampling. Temperatures were then taken to the nearest one-tenth of a degree Centigrade. The apparent rounding off of maximum temperatures during the survey is a result of readings to the nearest half degree during the summer of 1963.

Biological Sampling: Specimens were captured with an otter trawl of 1-1/2 inch mesh stretched measure with a 16-foot corkline. The same mesh size is used by commercial fishermen in the inshore waters during the shrimping season. After a ten-minute tow at each station, all specimens were bagged, placed on ice, and returned to the laboratory to be frozen. An attempt was made to make monthly collections within a short time period. For each species we recorded by tow the total number and total weight, with individual length-weight and length-frequency data for the major species, including the croaker and spot. When large numbers of a species were taken in one haul, individual lengths and weights were recorded for a randomly selected sub-sample of twenty specimens. Total length was taken to the nearest millimeter, weight was recorded to the nearest one-tenth gram.

Gear Limitations: The trawl was towed by a 23-foot inboard boat, at an estimated speed of two knots. Actual speed of the trawl over the bottom was influenced by tidal currents, wind direction, bottom type, and other extraneous variables. However, otter trawl tows provided the best available index of abundance, and it is hoped, but not assumed, that variations in speed were sufficiently random to prevent bias.

The relatively small size, large mesh, and operating principle of the trawl make it rather selective. Because of the large mesh size, smaller individuals were undoubtedly not represented in proportion to their actual numbers. An unknown percentage of large individuals were, in all likelihood, also able to escape capture because of their speed, the small size of the net, and the slow speed of towing.

Treatment of the Data: The data are presented chronologically in bi-monthly groups because of a desire to have complete areal sampling of the bay in each time unit. Except for length measurements, data from stations sampled twice during a bi-monthly period were averaged to provide one mean for each station for that period. When only one sample was collected, it was assumed to be representative of the fauna at that station during the two-month period.

Seasonal and areal abundance and distribution are presented by species both in terms of percent of biomass and catch per unit of effort (catch taken in one ten-minute tow). Graphs of the bi-monthly species mass and the distribution of spots and croakers whos "biopleths" based on catch per unit of effort at each station. Three dimensional graphs by season and depth showing the density of spots and croakers relative to all vertebrates collected, are based on weighted percentages with each bi-monthly figure representing one-hundred percent of the total vertebrate catch for that period.

Length-frequency curves for the two species (in 5 mm units) are shown in percentages instead of total numbers to give equal weight to each sampling period.

The data were analyzed on a Univac 1107 computer at the University of Alabama Computer Center in an attempt to correlate size with depth, temperature, and salinity. One data card was punched for each fish collected showing length, weight, depth, salinity, temperature, total number in sample, total species mass in sample, bottom type, day, month, and station number. Correlation coefficients were determined by a University of Pennsylvania computer program written in Fortran IV.

one mean for each station for that period. When only one sample was collected, it was assumed to be representative of the fauna at that station during the two-month period.

Seasonal and areal abundance and distribution are presented by species both in terms of percent of biomass and catch per unit of effort (catch taken in one ten-minute tow). Graphs of the bi-monthly species mass and the distribution of spots and croakers whos "bioplots" based on catch per unit of effort at each station. Three dimensional graphs by season and depth showing the density of spots and croakers relative to all vertebrates collected, are based on weighted percentages with each bi-monthly figure representing one-hundred percent of the total vertebrate catch for that period.

Length-frequency curves for the two species (in 5 mm units) are shown in percentages instead of total numbers to give equal weight to each sampling period.

The data were analyzed on a Univac 1107 computer at the University of Alabama Computer Center in an attempt to correlate size with depth, temperature, and salinity. One data card was punched for each fish collected showing length, weight, depth, salinity, temperature, total number in sample, total species mass in sample, bottom type, day, month, and station number. Correlation coefficients were determined by a University of Pennsylvania computer program written in Fortran IV.

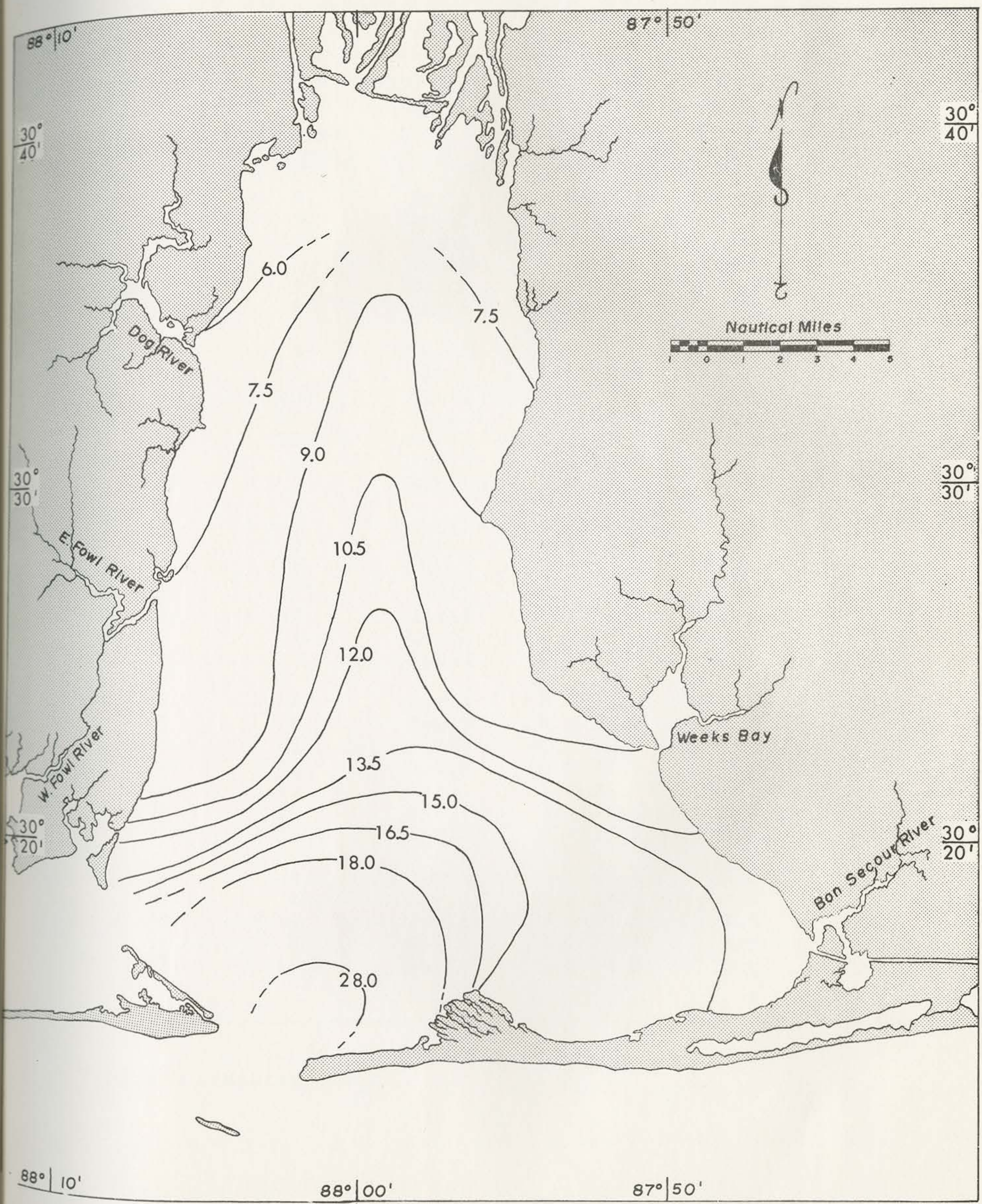
SALINITY

Mobile Bay exhibits a salinity pattern attributable to coriolis effect typical of northern Gulf Coast estuaries. According to Austin (1954), major tidal currents flow into Mobile Bay in an easterly and northerly direction towards the Bon Secour Bay area. At the same time, discharge from the major rivers emptying into Mobile Bay flows down the western side, causing lower salinities in the western part of the bay. This is aggravated by submerged spoil banks placed along the western side of the ship channel which greatly decrease the flow of high salinity channel water toward the western side. The combined result of these factors is a counter clockwise inverse salinity gradient from southeast to north in eastern and upper Mobile Bay. Salinity gradients in lower western Mobile Bay are effected to a considerable extent by high salinity water from Mississippi Sound.

Mobile Bay isohalines (Figure 3) are based on mean annual bottom salinity at each station, excluding those in the ship channel. The minimum number of observations was seven per station, and the maximum none during the one-year sampling period. The influence of Mississippi Sound can be seen readily, as can the major pattern of tidal intrusion into the bay. Thus, the 9 o/oo isohaline extends eight miles farther north on the eastern side than on the western side of the ship channel.

Salinity data are inadequate for detailed analysis, but can be utilized in evaluation of biological data. Absolute ranges and means of bottom salinities at each station, (Table 3) indicate large salinity fluctuations. For example, station 1, which had the lowest maximum salinity, still exhibited a range of 15.5 o/oo. Station 32 at a depth of nineteen feet near the mouth of the bay, exhibited a range of 31.5 o/oo. The channel stations, numbers 3, 10, 17, and 24 displayed the most stable salinity pattern. Only the two channel stations in the upper bay exhibited any appreciable variation. This was during an extremely heavy flood. Highest salinities throughout the bay occurred in October, the lowest in March and April. During the spring, all areas of the bay, except the deeper water in the ship channel, were practically fresh.

FIGURE 3. Bottom isohalines in Mobile Bay based on the mean salinity for May, 1963 through April, 1964, at all sampling stations. (Excluding ship channel).



88° 10'
87° 50'
30° 40'
30° 30'
30° 20'
Nautical Miles
1 0 1 2 3 4 5
Dog River
E. Fowl River
W. Fowl River
Weeks Bay
Bon Secour River
6.0
7.5
7.5
9.0
10.5
12.0
13.5
15.0
16.5
18.0
28.0
88° 10'
88° 00'
87° 50'

Table 3. Bottom salinities in Mobile Bay

Station Group	Station	Depth (feet)	Month of Low	Range (p.p.t.)	Month of High	Annual Mean (p.p.t.)
A	1	4	April	0.8-16.3	Nov	6.4
	2	8	April	0.5-17.1	Nov	6.8
	3	42	April	13.3-31.6	Nov	25.4
	4	12	March	0.1-19.6	Oct	9.3
	5	8	March	0.2-20.4	Oct	7.8
	6	4	March	0.1-20.0	Oct	7.4
B	7	4	April	1.4-19.6	Nov	7.4
	8	9	April	1.3-19.4	Nov	8.2
	9	13	April	0.9-23.6	Nov	9.3
	10	42	June [1]	16.5-32.4	Nov	27.3
	11	12	April	0.2-23.2	Oct	11.4
	12	9	April	0.3-23.2	Oct	9.2
	13	5	April	0.4-22.7	Oct	8.9
C	14	4	April	0.3-18.0	Nov	7.8
	15	9	April	0.4-19.1	Oct	7.7
	16	12	April	0.3-22.8	Nov	8.7
	17	42	April	26.1-32.9	Nov	30.8
	18	13	April	0.1-27.3	Jan	13.0
	19	8	March	0.0-23.4	Oct	9.8
	20	4	April	0.9-23.8	Oct	10.3
D	21	4	April	0.4-23.2	Dec	13.5
	22	9	April	0.2-26.0	Oct	15.1
	23	13	April	0.2-31.0	Oct	20.1
	24	42	March	28.0-33.9	Jan	30.9
	25	12	April	0.2-28.0	Oct	16.9
	26	10	April	0.2-25.6	Nov	13.8
	27	4	April	0.8-25.0	Dec	12.2
E	28	8	April	3.4-26.4	Dec	13.5
	29	5	April	1.2-24.1	Oct	13.3
	30	9	April	0.6-25.2	Oct	14.3
	31	4	April	1.2-24.9	Oct	13.9
	32	19	April	1.5-34.0	Aug	28.2

[1] Probable sampling error

TEMPERATURE

Bottom water temperatures (Table 4) ranged from a low of 6.6°C in January to a high of 31°C in July. The greatest temperature decline occurred from October to November and the greatest increase in March and April. Loesch (1965) reported a bottom temperature range from 8.5°C in January to 32.0°C in August during the period July, 1953 through August, 1955. Loesch's bottom temperature extremes were taken from bay stations about eleven feet in depth. During his survey the greatest temperature decline occurred in October, the sharpest increase in March and April.

The mean bi-monthly bottom temperatures for stations in shallow, medium, and deep areas of Mobile Bay are shown in Figure 4. Wide fluctuations occurred in the 0-6 and 7-15 foot depth group, as would be expected. The bi-monthly mean in the ship channel ranged from 11.5°C to 28.0°C as compared to 9.0°C to 29.8°C for shallow stations.

While the channel exhibited wide seasonal fluctuations, the changes were more gradual than in the surrounding shallow waters, and were most likely related to temperature changes in nearshore Gulf waters, rather than in the surrounding estuarine waters. For example, in the "E" station group in Table 4, all lows were recorded on the same day, with station 32, having the highest temperature, located nearest the entrance to the bay. The ship channel provides a more stable environment in respect to temperature (and salinity), than does the surrounding bay, and may serve as a haven for some species when environmental extremes in shallower water bring about physiological stress.

FIGURE 4. Bi-monthly variation in average bottom temperatures at shallow, medium, and deep stations in Mobile Bay from May, 1963 through April, 1964.

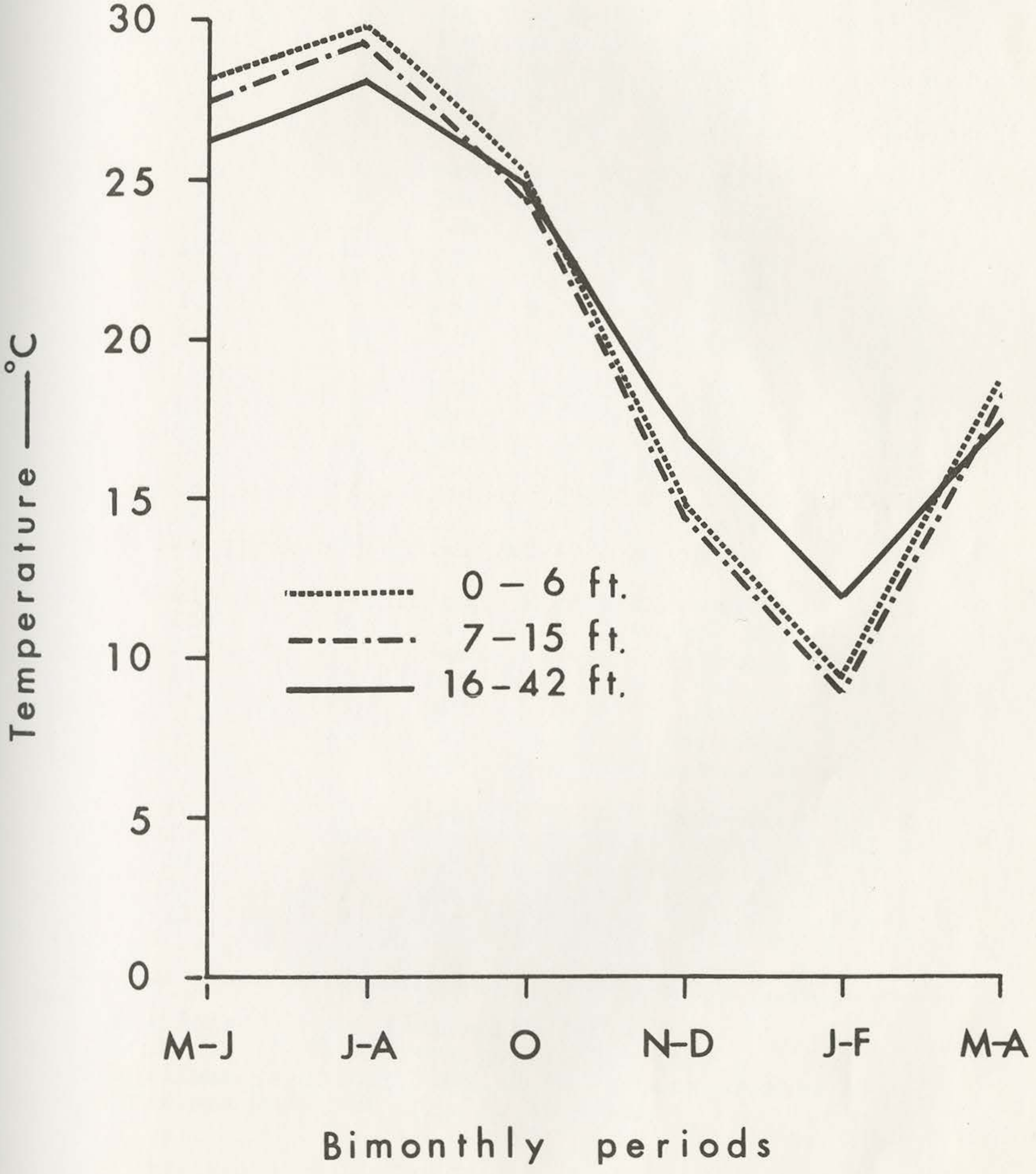

30
25
20
15
10
5
0
Temperature —— °C
0 – 6 ft.
7–15 ft.
16–42 ft.
M–J
J-A
O
N–D
J-F
M-A
Bimonthly periods

Table 4. Bottom temperatures in Mobile Bay [1]

Station Group	Station	Depth (feet)	Month of Low	Range °C	Month of High	Annual Mean °C
A	1	4	Feb	9.7-32.0	July	20.8
	2	8	Feb	8.8-31.0	Aug	20.1
	3	42	Feb	13.0-29.5	Aug	20.9
	4	12	Feb	9.6-31.0	July	20.3
	5	8	Feb	9.4-29.5	July	20.3
	6	4	Feb	9.5-31.0	July	21.0
B	7	4	Feb	10.2-30.0	July	22.1
	8	9	Feb	10.0-30.0	July	20.2
	9	13	Feb	9.4-29.5	July	20.0
	10	42	Jan	12.6-29.0	July	21.0
	11	12	Jan	9.9-28.5	July	19.8
	12	9	Feb	9.7-29.0	July	20.1
	13	5	Jan	10.9-28.5	June	20.8
C	14	4	Mar	17.0-29.0	July	24.1
	15	9	Mar	17.2-29.0	July	23.6
	16	12	Mar	15.6-29.0	July	23.7
	17	42	Jan	9.7-28.0	July	20.7
	18	13	Jan	10.7-30.0	July	20.8
	19	8	Jan	10.9-30.0	July	21.6
	20	4	Jan	11.4-31.0	July	22.0
D	21	4	Jan	9.4-29.0	June	22.2
	22	8	Jan	12.0-29.0	July-Aug	22.6
	23	13	Jan	9.0-29.0	July-Aug	21.4
	24	42	Jan	10.5-29.0	Aug	23.0
	25	12	Jan	6.7-29.5	Aug	21.7
	26	10	Jan	6.3-29.5	June-Aug	22.1
	27	4	Jan	5.6-30.0	June-July	23.1
E	28	8	Jan	6.5-29.0	June-July	21.9
	29	5	Jan	6.9-31.0	July	22.6
	30	9	Jan	6.8-30.0	June-July	22.2
	31	4	Jan	7.2-30.0	June-July	22.7
	32	19	Jan	11.2-29.0	July	22.1

[1] Stations 1-7 not sampled in January
Stations 17-32 not sampled in February
Stations 14-16 not sampled in January or February
Stations 4-20 not sampled in August

BIOLOGY OF THE CROAKER

Spawning Period: Because the mesh size of the trawl precluded the capture of larval or postlarval croaker, the data are of limited use in determining spawning periods. Bell[2] collected croakers of less than 25 mm total length at marsh seining stations in western and upper Mobile Bay from November, 1965 through February, 1966, and noted that they appeared in large numbers in January. Data from a 1965-66 estuarine survey (on file at the Alabama Marine Resources Laboratory)[3] show young-of-the-year croakers (1-4 cm) in the upper bay in November, with croakers (very small) less than 20 mm in total length being taken as late as April. The author collected small croakers (12-15 mm total length, with an average of 13 mm) from peripheral marsh areas of Mobile Bay on October 11, 1966, strengthening Roithmayr's (1965b) conclusion that spawning begins off the northeastern Gulf coast in September. From quantities of ripe fish found in the eastern Gulf from September through November, he assumed this to be the principal spawning period.

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2 Data taken from a thesis in preparation by John L. Bell, Jr. on Mobile Bay peripheral marsh as a habitat fro commercial marine species is referred to in this paper as Bell (personal communication).

3 Trawl data for Nov., 1965 - Oct., 1966 estuarine survey of Mobile Bay and Mississippi Sound is referred to in this paper as (data on file).

Spawning periods for various Atlantic and Gulf localities are given in Table 5. Apparently, spawning in the Gulf starts at about the same time as along the coast of the South Atlantic states. However, the Atlantic coast shows a longer spawning peak than that reported for the Gulf, and possibly, Atlantic spawning peaks occur in both fall and spring as theorized by Haven (1957), while only one prolonged fall and winter spawning occurs in the warmer Gulf waters.

<u>Spawning Location</u>: Roithmayr (1965b), in observing large numbers of croakers caught in nearshore and offshore areas of the northern Gulf throughout the year, found quantities of ripe fish in the northeastern Gulf from September through November. Forty-three percent of the croakers collected in three to seven fathoms off the coasts of Alabama, Mississippi, and eastern Louisiana were either ripe or ripening in October. In October, 1963 inshore samples from Mobile Bay and Mississippi Sound, 97 percent of the fish were virgin, the remainder were either in spawning condition or spent.

The author collected croakers in Mississippi Sound in October, 1966, with running milt and roe. These fish, taken about three miles inside the pass between Dauphin and Petit Bois Islands, were in fairly deep, high salinity water and might have been migrating towards the pass.

Pearson (1929) stated that croakers spawn in the open Gulf near the mouths of passes leading into

Table 5. Spawning period of croakers along the Atlantic and Gulf coasts

Locality	Spawning Period	Presence of Young (less than 30 mm)	Peak of Spawning	Peak Abundance of Young	Authority
Texas	Late Fall	Oct-Apr		Nov	Pearson (1929)
Texas		Nov-Apr			Gunter (1945)
Louisiana	Oct-Jan	Nov-Apr			Suttkus (1955)
Mobile Bay	Sep-Feb	Nov-Feb		Jan	John Bell (personal communication)
Mobile Bay		Oct-Apr			Data on file
Northeast Gulf			Sep-Nov		Roithmayr (1965b)
Tampa Bay		Mar			Springer and Woodburn (1960)
South Carolina	Fall & Winter	Oct-May	Oct-Jan		Bearden (1964)
North Carolina	Sep-May	Sep-May	Oct-Mar	Oct-Mar	Hildebrand and Cable (1930)
Virginia		Sep-Apr			Haven (1957)
New Jersey	Aug-Dec	Sep-Mar (40 mm)			Welsh and Breder (1923)

the shallow bays and lagoons of Texas. Gunter (1945) found few ripe fish inside Texas bays. Haven (1957) postulates that spawning probably occurs in the ocean near the mouth of Chesapeake Bay. Bearden (1964) reports mature croakers in spawning condition from several miles to fifty or sixty miles offshore in South Carolina. Hoese (1965) collected larval croakers at along-shore stations in Texas in excess of fifteen miles from the nearest pass, and suggests that larvae might be swept away by alongshore currents if spawning were localized at the inlet mouth, while spawning over a large area might insure at least some reaching the bay.

The bulk of spawning undoubtedly takes place offshore, although croakers will probably spawn inside deep passes if favorable conditions exist. It would appear that spawning in the northeastern Gulf takes place over a rather wide area, not localized around the mouths of passes.

Age, Growth, and Movement: Bi-monthly deviations from the mean annual length-frequency curve are shown in Figure 5. Two age groups are dominant in the bay. The 0 age class spawned in the fall of 1962 had a modal length of 95 mm in May and June. The 1961 I age class had a mode at 146 mm. Apparent slow growth of the 0 age class in July and August may be attributed to larger members of that group emigrating offshore. In October, when the 0 age class reached one year of age, the mode was at 117 mm. This figure falls short of sizes given by Gunter (1945) in Texas, Suttkus (1955) in Louisiana, and Hildebrand and Cable (1930) in North Carolina

(Table 6). Suttkus (1955) shows a mean of 104.7 mm in October 1954, but other reports all show considerable greater growth than for Mobile Bay. Bell (personal communication) shows growth rates for Mobile Bay in 1966 comparable to that of Suttkus' slow growth year which agrees with the hypothesis of Springer and Woodburn (1960) that different growth rates are found within systems as well as between major bay areas. Furthermore, Gunter, Suttkus, and Hildebrand and Cable, give the arithmetic mean length of the age group, which does not give as accurate an estimation of the growth rate of a fish with a widely skewed length range as does the mode. Either this is the case, that growth was slower in Mobile Bay than in the other areas, or larger members of the 0 age class left the bay as they approached one year of age.

Growth was slow from October to March-April of 1964 (Figure 5); the principal year class mode increasing from 117 to 132 mm. The I age class, fairly abundant in May and June, and less abundant in July and August, disappeared almost entirely from the bay by October, and was taken only occasionally the rest of the year. The modal size of this I age class increased from 146 mm to 157 mm during the two bi-monthly periods, showing moderate growth. Young of the year from the 1963 autumn spawning first appeared in the trawl catches in January and February, 1964, reaching a mode of 60 mm in March and April. This size is less than those given in Table 6.

FIGURE 5. Bi-monthly per cent deviation from the yearly mean length-frequency of croaker in Mobile Bay.

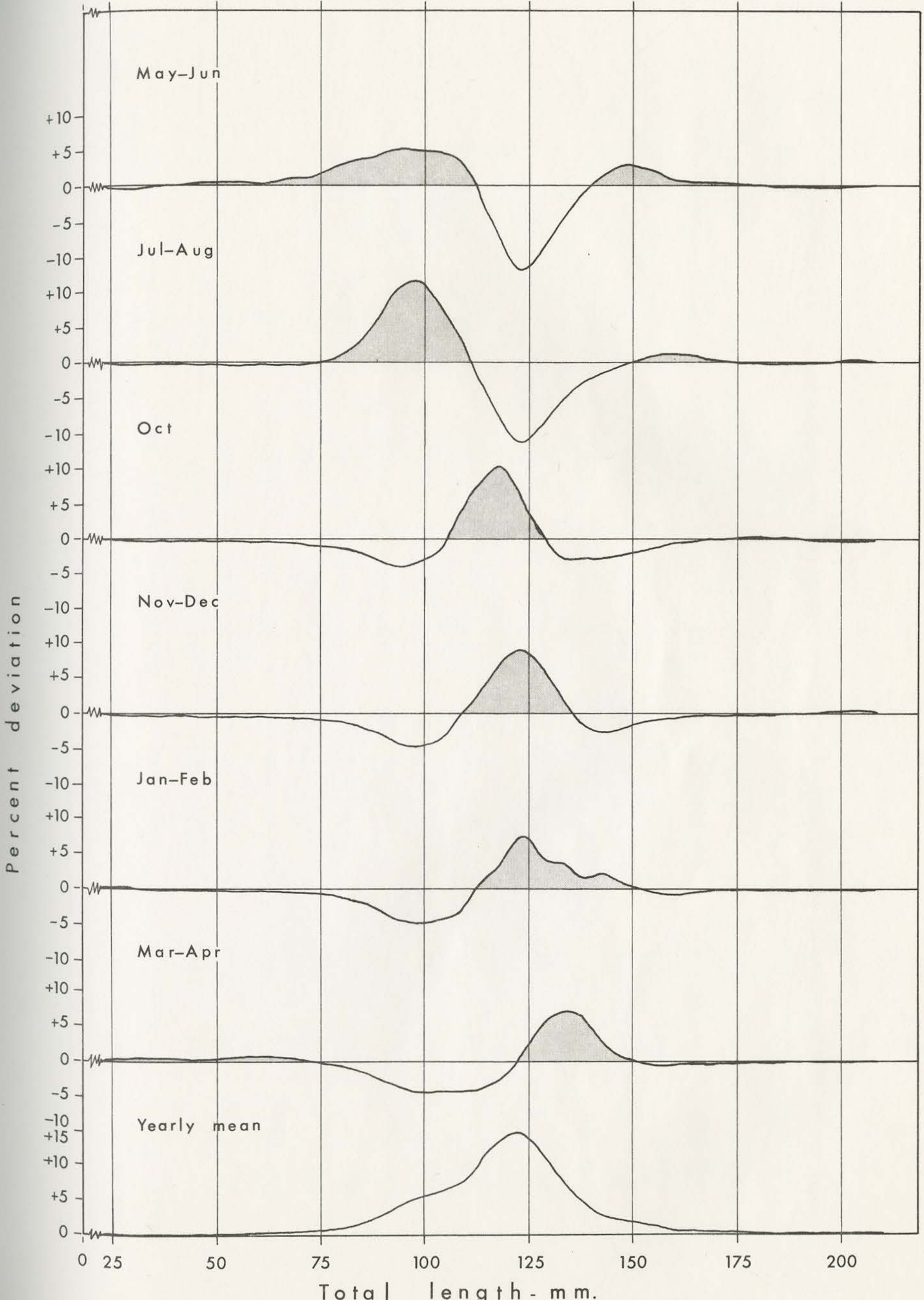

May–Jun
Jul–Aug
Oct
Nov–Dec
Jan–Feb
Mar–Apr
Yearly mean
Percent deviation
+10
+5
0
-5
-10
+15
0
25
50
75
100
125
150
175
200
Total length - mm.

Table 6. Mean total lengths of "0" age class of croaker from different localities (modified from Springer & Woodburn, 1960, Table 15) [1]

Source	Gunter (1945)		Suttkus (1955)		Nelson		Bell[2]	Springer & Woodburn (1960)	Hildebrand & Cable (1930)
Area	Texas		Louisiana		Mobile Bay		Mobile Bay	Tampa Bay	N. Carolina
	1941	1942	1953	1954	1963	1964	1966		
Mar	----	----	-----	-----	----	----	----	----	-----
Mar-Apr	----	----	-----	-----	----	60	----	----	-----
Apr	78	88	-----	65.0	----	----	60	28.5	-----
May	88	95	-----	65.8	----	----	68	46.0	-----
May-Jun	----	----	-----	-----	95	----	----	----	-----
Jun	93	118	-----	74.8	----	----	76	73.4	72.1
Jul	113	----	102.7	86.5	----	----	83	89.7	95.8
Jul-Aug	----	----	-----	-----	97	----	----	----	-----
Aug	123	118	116.6	94.6	----	----	92	----	110.6
Sep	128	----	126.5	104.2	----	----	----	----	132.7
Oct	143	----	145.5	104.7	117	----	----	----	143.4
Nov	138	----	152.8	-----	----	----	----	----	-----
Nov-Dec	----	----	-----	-----	121	----	----	----	-----
Dec	----	----	-----	-----	----	----	----	----	-----

1 Tampa Bay data are standard lengths. Mobile Bay data from Nelson are modal lengths.

2 Bell, personal communication

As has been pointed out, the gear was highly selective against small fish, and the actual mode of the 1963 year class was probably less than indicated by the data.

Only two age groups are found in abundance in the summer and fall as they approach two years of age, and 0-age-class fish enter the bay during the winter, where they remain throughout their first year. When coupled with offshore data, it is possible to follow the development of three age groups. Bi-monthly length-frequency distributions for Mobile Bay are shown in Figure 6, together with offshore length-frequency curves by three-month periods from Roithmayr (1965b, Figure 5). Offshore data for the spring of 1964 were provided by Roithmayr (personal communication). Length frequencies for July and August show fish of the 0, I, and II age classes from offshore, and fish of the 0 and I age classes from inshore. The larger members of the 0 age class appear to have emigrated offshore, providing an explanation for the apparent lack of growth within the bay in July and August. The majority of the one-year-old fish also emigrated offshore. The most numerous offshore portion of the population is predominately two year olds approaching three years of age. Figure 6, shows July and August modes at 95, 150, and about 180 mm. Offshore modes approximate 165-175 mm for September - November, and this is assumed to be the size reached at two years of age.

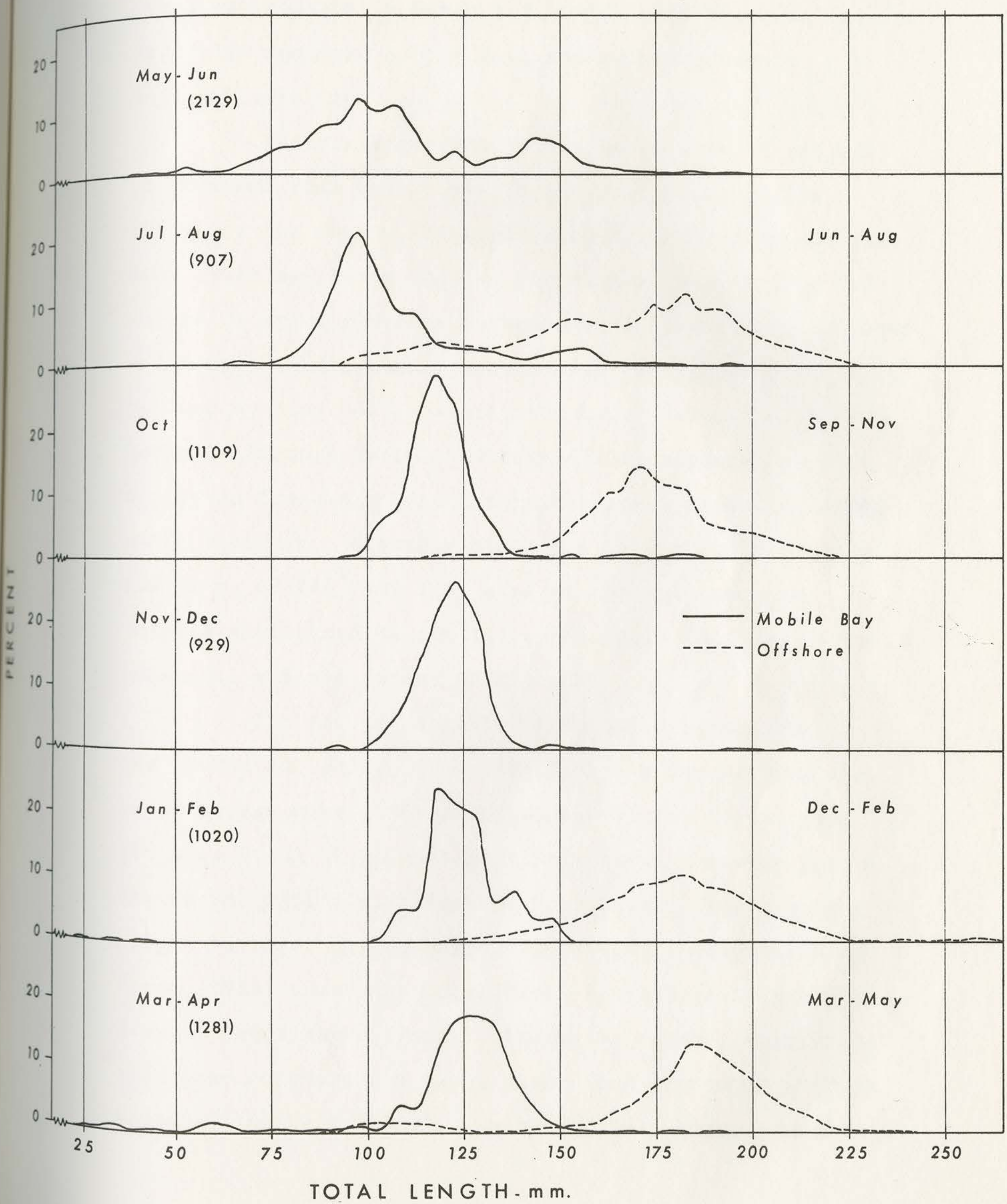
Roithmayr's data shows fish of the 0 age class present offshore both in the spring and summer of 1962, and in the summer of 1963. A few were also taken in the summer of 1961. Apparently a small percentage of 0-age-class fish leave the bay every summer for nearshore areas of the Gulf. Using fish traps at Cedar Bayou, Texas, Simmons (1951) reports that many croakers less than one year old appear to move into Gulf waters in May and June.

By October, practically all older fish have left the bay. Those which emigrated during the summer and fall are those approaching the age of two which are about to spawn for the first time Roithmayr (1965b).

Three-year-old fish, which were dominant offshore as age group II in the summer rapidly disappeared from the catch. Gunter (1945) found few three-year-old fish in Texas. Suttkus (1955) found out of 25,081, only a few croakers he estimated were three years of age. Roithmayr (1965b) reports that fish presumably three years of age were taken by the exploratory fishing vessel Oregon in November, 1961, at a depth of 30 to 40 fathoms. Three-year-old fish evidently migrate farther offshore than the commercial fishing area or die, for they disappear from the commercial catch when they approach that age.

A few 0-age-class fish enter the bay catch in January and February, while a small portion of the one year olds are being taken in the offshore catch. Roithmayr (1965c) shows a sharp decline in the average weight of croakers caught near shore in the Gulf in January. This drop in weight was caused by the movement of one-year-old fish out of the bays, and migration of

FIGURE 6. Bi-monthly length-frequency percentages of croaker in Mobile Bay, and offshore in the northern Gulf of Mexico (offshore data provided by Charles M. Roithmayr, personal communication).


May - Jun
(2129)
Jul - Aug
(907)
Jun - Aug
Oct
(1109)
Sep - Nov
Nov - Dec
(929)
Mobile Bay
Offshore
Jan - Feb
(1020)
Dec - Feb
Mar - Apr
(1281)
Mar - May
PERCENT
0
10
20
25
50
75
100
125
150
175
200
225
250
TOTAL LENGTH - mm.

the two-year-old fish to deeper water. Figure 6 shows three age classes in March and April, with zero and one year olds dominant in the bay, and two year olds dominant offshore.

There are apparently two major outward periods of movement from Mobile Bay to the Gulf waters. The first, in the winter, involves fish slightly over one year old. They may leave the bay for warmer, more stable Gulf waters to avoid rigorous environmental conditions. Simmons and Hoese (1959), sampling with tide traps, reported no outward movement of croakers from Cedar Bayou, Texas from November through March. Suttkus (1954) reported a slow migration from Lake Pontchartrain which apparently lasted until February. Possibly older and larger individuals of the young of the year lose some of the tolerance to varying environmental conditions characteristic of juvenile croakers, and are forced to migrate.

The second period of emigration occurs during the summer and fall. In Mobile Bay fish approaching two years of age move offshore to spawn for the first time (Figures 5 and 6). Copeland (1965) shows a steady year around emigration from Aransas Pass Inlet, Texas, with a slight increase during May through August. Simmons and Hoese (1959) show mass emigration of croakers from May to July at Cedar Bayou, Texas. The major croaker emigration from Lake Ponchartrain takes place from September through November (Suttkus, 1954). Bearden (1964) reports major offshore movement of croakers from June to November in South Carolina. A lesser portion of the summer emigration from Mobile Bay was composed of larger members of the 0 age class, which apparently returned to the bay in the fall.

Abundance and Seasonal Distribution: Croakers were the most abundant fish taken during this study. Of 16,043 fishes taken from Mobile Bay, croakers were 46 percent by number and 40.5 percent by weight. Subsequent catches in Mobile Bay in 1966 (data on file) using a small mesh trawl, show the croaker to rank a poor second in abundance in open bay areas to the bay anchovy, *Anchoa mitchelli*. However, wherever relatively large mesh trawls have been used, the croaker ranks first in abundance in the northern Gulf. Simmons and Hoese (1959) reported 198,352 croakers taken in tide traps at Cedar Bayou, Texas compared to 29,107 for the second most abundant species during 1950-51. Gunter (1945) found the croaker to be the fish taken most frequently in otter trawl samples in Texas. Perret (1966) reports the croaker to be predominant in Vermillion Bay, Louisiana, trawl samples. However, Rounsefell (1964) found the croaker to rank second in abundance to spot in trawl samples from Lake Borgne to Breton Sound, Louisiana. Croakers comprise 56 percent, by weight, of the bottom fish catch east of the Mississippi River delta nearshore, and 55 percent of the offshore catch Roithmayr (1965a). According to Bearden (1964) croakers ranked second in trawl catches in South Carolina inshore waters. Gunter and Hall (1965) found the croaker to rank fourteenth in abundance in the Caloosahatchee estuary of Florida.

Croakers were taken in 83 percent of all trawl samples in Mobile Bay; the number per tow remained fairly constant throughout the year, (Table 7). The lowest catch per unit of effort occurs in July and August. It has been suggested that the larger individuals of the 0 age class migrated out of the bay during that period. A sharp increase in the October catches may indicate that these fish return to the bay, since no major juvenile or adult recruitment, occurs at the time. While catches fluctuated somewhat throughout the rest of the year, the degree of fluctuation was not great and might be expected. The large catches in January and February may be explained by the fact that croakers were concentrated in the ship channel, which was sampled heavily in relation to its area, as compared to other portions of the bay.

Roithmayr (1965c) reports a decrease in average weight per fish nearshore in April, along with increased abundance, indicating recruitment from the bays which might account for the decreased abundance in the bay during that period as shown in the table.

Seasonal distribution of croakers in Mobile Bay is based on catch per unit of effort (Figure 7). While catch by weight provides no information on seasonal size distribution, it does show major concentrations and distributional patterns. The figure shows a relatively low density of croakers in eastern Bon Secour Bay throughout the year, and a low density along the Mobile Bay periphery during all months except for spring. In general, croakers are widespread throughout the bay in warmer months with heaviest concentrations along the middle of the bay in deeper water. In colder months, they leave shallow and moderately deep areas, concentrating in and near the ship channel.

The abundance of croakers in the ship channel in January and February is quite striking. The light concentration in the upper bay is primarily composed of fish less than one year old. Haven (1957), Welsh and Breder (1923), Suttkus (1954), and Bearden (1964) all found larval and young fish remaining in the upper reaches of estuaries throughout the winter.

A small area of high croaker density was present in the south-west portion of the bay throughout most of the year, and may reflect the influence of Mississippi Sound.

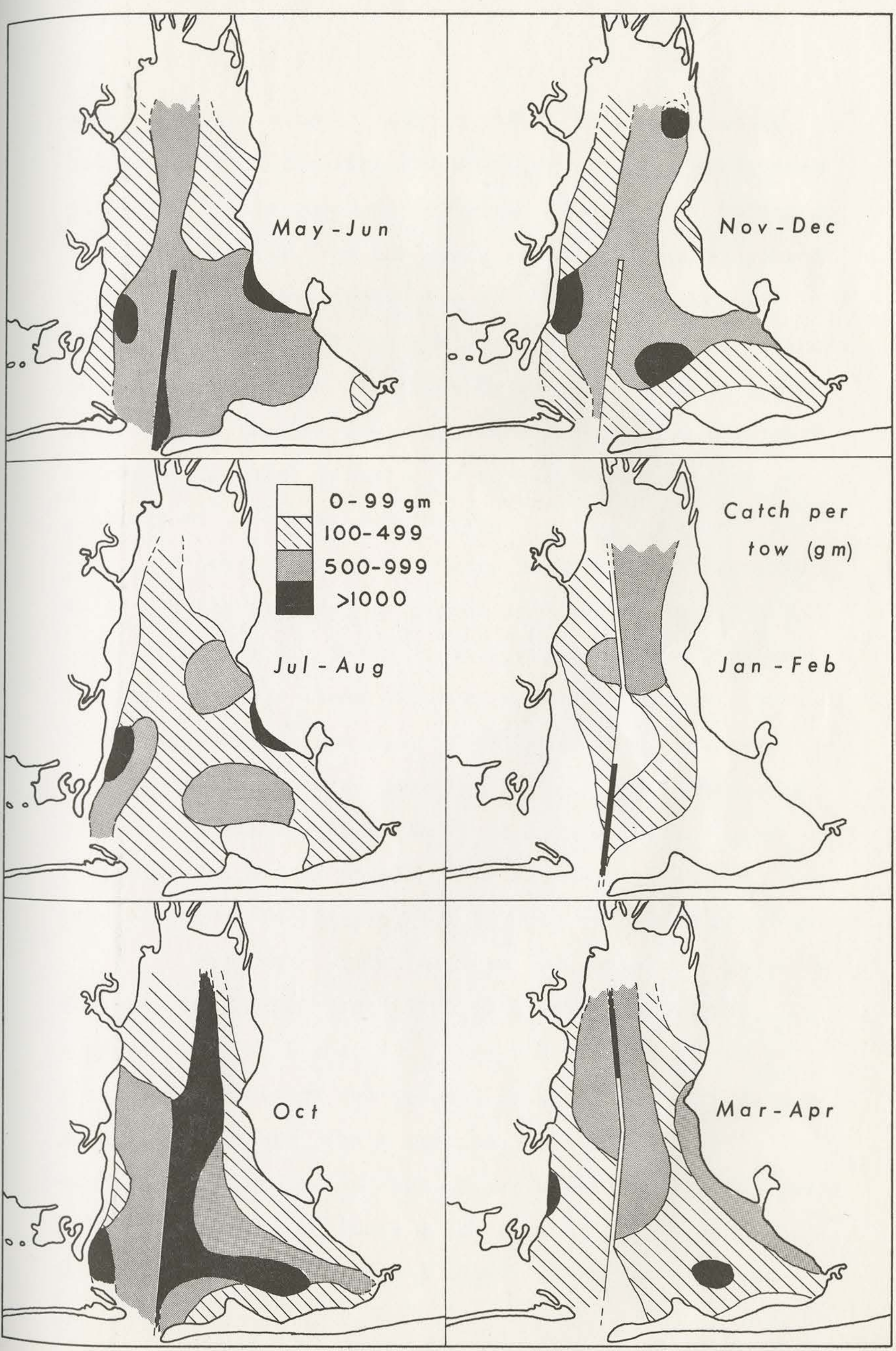
Relation of Croaker to Salinity: The relationship between the size distribution of croakers and salinity has been discussed at length in the literature, but few documented conclusions have been established. Bearden (1964) indicates, with reservations, that salinity has a major influence on the size distribution of croakers in

Table 7. Bi-monthly catch per tow and percentage of croaker in Mobile Bay trawl samples, and percentage of offshore catch May, 1963 - April, 1964. [1]

	Mobile Bay					Offshore
	Frequency of occurrence in samples	Number per tow	Total catch by number	Catch per tow	Catch by weight	Total weight
	Percent		Percent	Grams	Percent	Percent
May-Jun	87.5	33.3	38.52	528.8	31.12	60.35
Jul-Aug	84.1	20.8	43.79	290.6	31.48	52.06
Sep-Oct	87.5	34.7	52.83	598.8	47.00	62.00
Nov-Dec	81.6	24.5	58.82	438.3	59.42	65.74
Jan-Feb	65.7	30.0	45.07	562.2	48.04	39.34
Mar-Apr	88.0	25.0	50.42	483.6	46.01	53.71
Annual Mean	83.3	28.1	45.84	479.9	40.49	56.36

[1] Offshore data provided by Roithmayr, personal communication

FIGURE 7. Bi-monthly areal distribution of croaker in Mobile Bay, based on catch per unit of effort.


May-Jun
Nov-Dec
0-99 gm
100-499
500-999
>1000
Catch per tow (gm)
Jul-Aug
Jan-Feb
Oct
Mar-Apr

South Carolina waters. Gunter (1945) shows a relation between size of croakers and salinity during a short-term period of little movement in Texas. Gunter used selected stations, however, and the small amount of data presented might not have been indicative of the overall picture. The effect of salinity on the size-distribution of croakers is discussed in some detail by Haven (1957). Reid and Hoese (1958) in East Bay, Texas indicate, but do not show conclusively, that salinity is not the cause of size gradient of croakers in estuaries.

Length ranges and modes of Mobile Bay croakers by bi-monthly periods at several salinity groupings are shown in Figure 8. There is an apparent relation between the mode of 0-age-class croakers and salinity until the fish reach one year of age. From January on, however, the mode appears to have no relation to salinity. This lack of size gradation with salinity is also evident in one year olds which were present from May through August, and were collected in all sampling periods in all salinity groups.

The correlations between the length of individual fish and the salinity at which they were caught were generally slight (Table 8). When the masking effect of I-age-class croakers was removed by migration of this age group from the bay, the 0 age class showed a higher correlation coefficient than at any other time of the year. This is evidenced in Table 8 for October and November - December. However, Figure 8 shows less of an apparent cline of 0-age-class fish during this period than in the summer. Separation of the two age groups would yield better information as to the effect of salinity on croaker distribution. The somewhat contradictory results of the table and figure show that larger croakers, while oriented towards higher salinities, are not necessarily confined to high salinity waters.

The interrelationship between salinity and other environmental factors must also be considered in evaluating the effect of any one parameter. For example, the correlation coefficients between length and salinity and between length and depth show an almost straight-line relationship when plotted against each other. The effects of other variables were not discounted in discussing each variable in this analysis, but the relation of any one variable to an estuarine organism such as the croaker must be viewed in conjunction with its interrelationships to other variables.

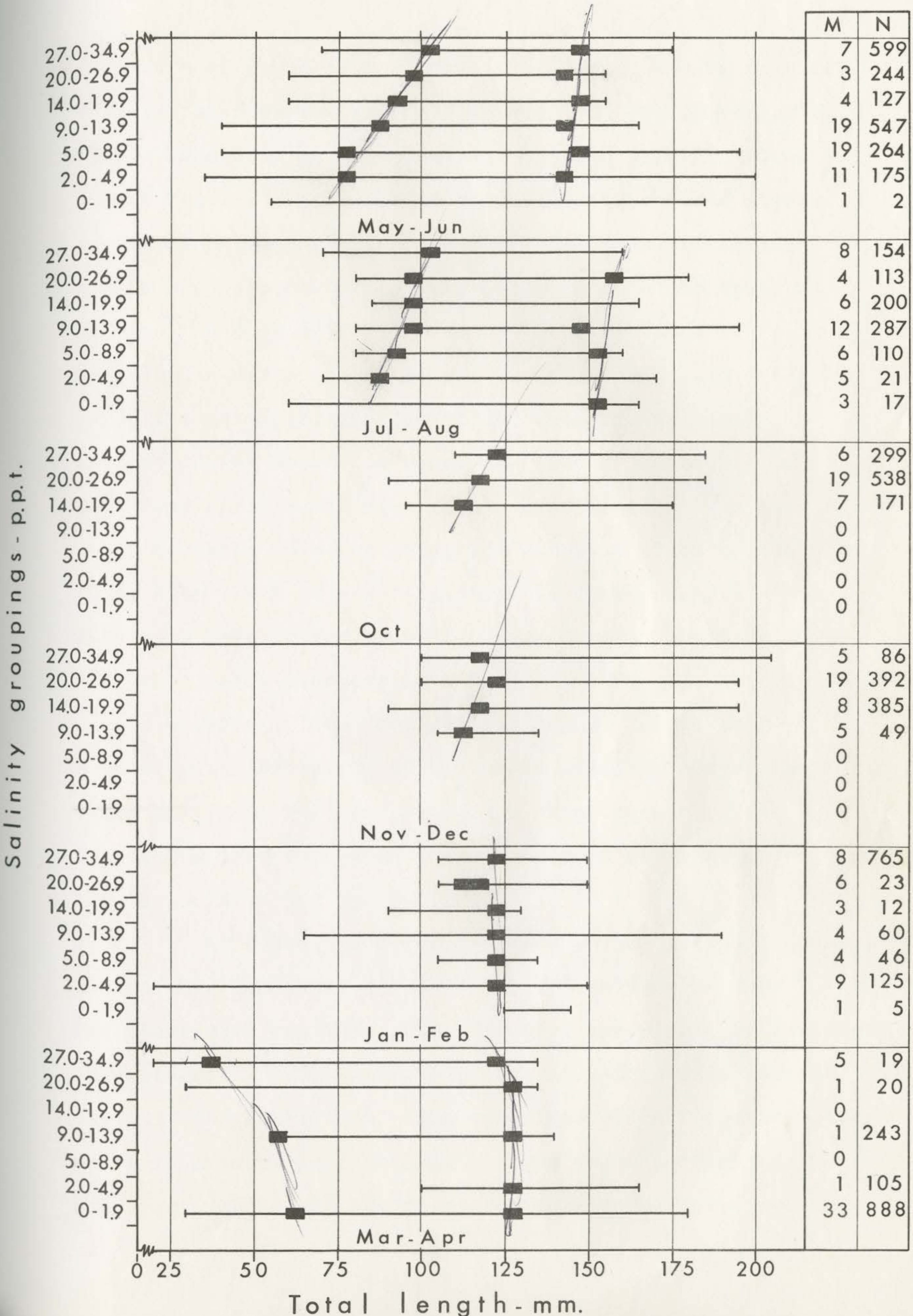
Croakers move slowly down the bay as they increase in size, and may move into higher salinity areas incidentally because of some other factor or combination of factors. Possibilities of this include theories on food preference, salt wedge transport, differential growth rates, and utilization of lower bay areas by the young of early spawners.

Haven (1958) feels that the probable explanation, in the York River, Virginia, is that larger fish are better able to resist upstream transport by a salt wedge, and are

Table 8. Correlation coefficients between individual lengths of croaker and salinity, temperature, and depth in bi-monthly time periods, May, 1963 -- April, 1964

Months	Number of Specimens	Correlation Coefficients		
		Salinity	Temperature	Depth
May-Jun	2,219	-.053	.036	-.084
Jul-Aug	907	-.119	-.171	-.063
Oct	1,109	.308	.153	.221
Nov-Dec	929	.257	.011	.138
Jan-Feb	1,020	.186	.118	.247
Mar-Apr	1,281	-.239	.053	-.180

FIGURE 8. Bi-monthly length ranges and modes of Mobile Bay croaker by salinity catagories. (Number of samples) (Number of specimens).



Salinity groupings - p.p.t.
Total length - mm.
M
N
27.0-34.9
20.0-26.9
14.0-19.9
9.0-13.9
5.0-8.9
2.0-4.9
0-1.9
May-Jun
Jul-Aug
Oct
Nov-Dec
Jan-Feb
Mar-Apr
0
25
50
75
100
125
150
175
200
7 599
3 244
4 127
19 547
19 264
11 175
1 2
8 154
4 113
6 200
12 287
6 110
5 21
3 17
6 299
19 538
7 171
0
0
0
0
5 86
19 392
8 385
5 49
0
0
0
8 765
6 23
3 12
4 60
4 46
9 125
1 5
5 19
1 20
0
1 243
0
1 105
33 888

able to move downstream gradually as they increase in size. This is based on the salt wedge theory of Pritchard (1951). Simply, there is an upstream flow of high salinity water in deeper estuarine areas under an outflowing surface stream. Austin (1954) reports that this situation exists in the Mobile Bay ship channel. This might explain the apparent reversal of size of 0-age-class fish in relation to salinity in March and April (Figure 8), since they would be using the net upstream flow in the ship channel as a transportation device to upper bay nursery grounds. However, March and April would seem to be rather late in the year for young croakers to be entering the estuary. Fish as small as 20 mm were taken in low salinities in January and February, with none being taken from the ship channel. Data on file show that small croakers were taken in parts of the upper bay in November, 1965, but did not appear in the ship channel until February, 1966. While the salt wedge hypothesis might hold true for the Mobile Bay ship channel, it is improbable that this would be the case in other areas of the bay, especially the western side.

According to Darnell (1958) in an excellent study on the food habits of fishes and invertebrates of Lake Pontchartrain, croakers pass through a succession of distinct food stages. There is a change in food preference between juvenile and adult fish. The juveniles prefer organic matter which is usually more abundant in the upper portion of estuaries, while the adults prefer bottom burrowers and larger mobile animals which are usually more abundant in the lower portion of estuaries. This could well result in an increasing size gradient of fish from the upper to lower bay, corresponding with increasing salinity, although increasing salinity would not be the causative factor.

Reid and Hoese (1958) suggest that smaller croakers are found farther up the bays because of food preference, or because of a behavior pattern in which the first arrivals from offshore spawning settle in lower reaches of the bay, with later arrivals leapfrogging the earlier ones.

Croakers were taken in salinities ranging from 0.0 o/oo to 34.0 o/oo in Mobile Bay, which represented the lowest and highest salinities recorded in the bay during the survey. Gunter (1961) reports croakers being taken in Grand and White Lakes, Louisiana, at salinities of 0.08 o/oo. Haven (1957) occasionally found larger numbers of croakers in water which had no appreciable trace of salt. Mobile Bay croakers were taken in large numbers in 33 samples in March and April in which the salinity was less than 2.0 o/oo. However, heavy flooding lowered the salinity throughout the bay during these months, and the ship channel was the only bay area with a relatively high salinity.

Overall data from the survey show that croakers were more abundant at higher salinities. An average of

38.4 fish per tow was taken in salinities of 14.0 o/oo and greater, as compared to an average of 19.2 fish per tow in salinities of less than 14.0 o/oo. In samples of 27.0 o/oo and greater, the number of croakers was 49.3 per tow. However, no low salinity stations were sampled during two of the periods, and the fact that all croakers were necessarily in high salinity waters may have biased the data.

Relation of Croakers to Temperature and Depth: Dispersal of croakers through the bay in warmer months, and heavy concentration in deeper portions of the bay in colder months has been discussed previously. The major concentration, despite wide dispersal, was near mid-areas of the bay throughout most of the year. The seasonal change in distribution is probably a direct result of temperature changes. Because of the interrelationship between depth and seasonal temperatures in Mobile Bay, and the movement of croakers into various depths, dependent on temperature, the two variables are discussed together.

The lowest temperature in which croakers were caught was 6.7°C, and then in only two of seven samples taken at a temperature of less than 8.0°C. Bearden (1964) reports croakers taken at a low of 7°C in South Carolina. Hildebrand and Cable (1930) concluded that young croakers are less sensitive to cold than older fish, and reported taking small croakers at Beaufort at 5°C which were numb, but did not suffer mortality. Croakers were taken at 31.0°C, the highest temperature recorded during the survey.

Croakers size in Mobile Bay showed no short-term relation to temperature. Bi-monthly correlation coefficients for individual length versus temperature are given in Table 8. The highest correlation occurred in January and February, when a few small 0-age-class fish were taken in shallow water, and a few larger individuals were taken in deeper water in upper Mobile Bay. As with temperature, no significant bi-monthly relationship was found between length of croakers and depth (Table 8). The slight negative correlations during warmer months tend to agree with the observations of Bearden (1964) that larger fish were found in shallow South Carolina waters in warm months in 1962, but few young croakers were found in depth of less than ten feet. The positive correlations during colder months tend to support the hypothesis that large croaker are less cold tolerant than smaller fish, hence are found in deeper, warmer areas during colder months.

Information is scarce on the growth rate of croakers in relation to temperature. Haven (1957), states that growth was apparently slow during the winter in the York River, conversely, Hildebrand and Cable (1930) at Beaufort, state, "The data show that young fish gain considerable growth during the winter..." The growth of croakers in Mobile Bay (Figures 5 and 6) was apparently slow, at best, throughout the winter, although that portion of the population which emigrated must be considerable.

The seasonal change in abundance distribution is probably caused more by temperature than any other single factor. Suttkus (1954) reports that decreased temperatures were directly correlated with the movement of fishes out of Lake Pontchartrain, and was possible the controlling factor. Bearden (1964) states, "Water temperatures appeared to have a direct effect on the migration of croakers to and from inside waters, particularily in the spring and fall of the year". Summer and fall emigrations from Mobile Bay were croakers going offshore to spawn, and the movement might either be considered directly or indirectly due to temperature. However, the mid-winter emigration is almost surely a result of low temperatures in shallow areas of the bay. The concentrating influence brought about by low temperatures is shown in Table 7 for January-February, where the catch per unit of effort did not decrease, but the percentage of occurrence in the number of trawl samples decreased sharply.

The seasonal distribution of croaker biomass by area and depth category is shown in Figure 9 a-f. The figure gives depth groupings, north to south transects across the bay (A-E), and the density of croakers relative to other vertebrates.

Greater concentrations were found in deeper areas of the bay during May and June, with croakers scattered randomly in July and August. Temperatures ranged one to two degrees Centigrade less in the ship channel than in other areas in warmer months. In October, bottom temperatures were similar throughout the bay, major concentrations of croakers occurred in medium and deep areas. They were found primarily at medium depth areas in November and December, after temperatures in shallow areas dropped below that of the ship channel.

The concentration in January and February (Figure 9e) is striking; out of 19.1 kg of croakers collected, 14.2 kg were taken from the ship channel in the lower bay. Temperatures in the ship channel during those months averaged over 2°C higher than in shallower areas. In March and April, croakers dispersed widely into shallow and medium depths, which had warmed considerably. A large concentration had also moved up the channel.

Croakers appear to prefer deep to shoal water if temperatures are nearly equal. In extreme cold weather croakers leave medium depth waters for the warmer ship channel, or seek warmer waters in the Gulf. Welsh and Breder (1923) state that young croakers appear to spend their first winter in the deeper waters of the larger bays, and in the ocean near inlets on the east coast of the United States. Haven (1957) reported that young croakers were often present in shallow water, but were apparently not as abundant as in the main channel in the York River. The need of deep areas in estuaries as a place of refuge from vigorous environmental conditions is discussed at length by Rounsefell (1963).

FIGURE 9. Relative density of croaker and spot to other vertebrates by depth groupings and north to south transects (A-E) in Mobile Bay.

A. May and June, 1963.

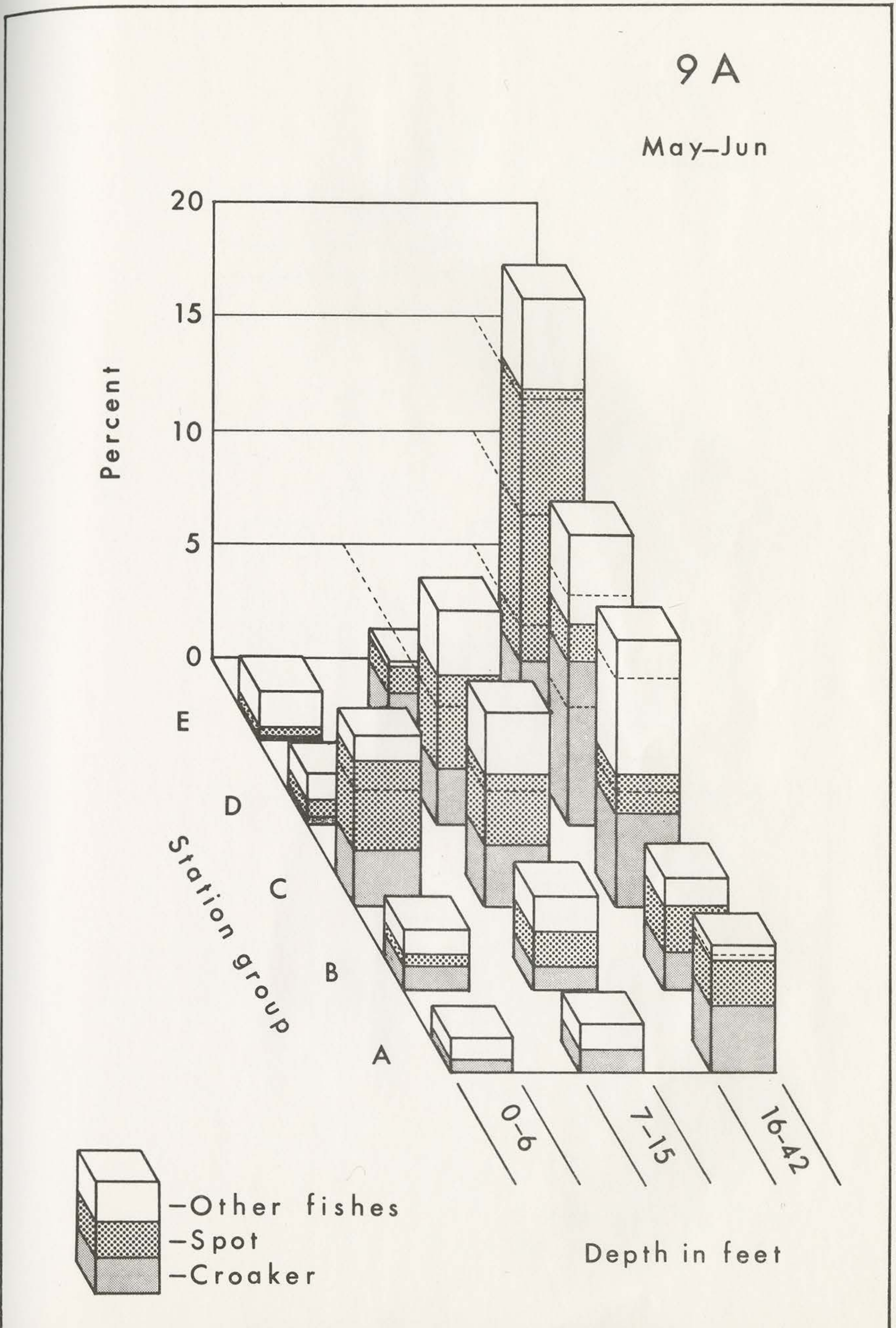
B. July and August, 1963.

C. October, 1963.

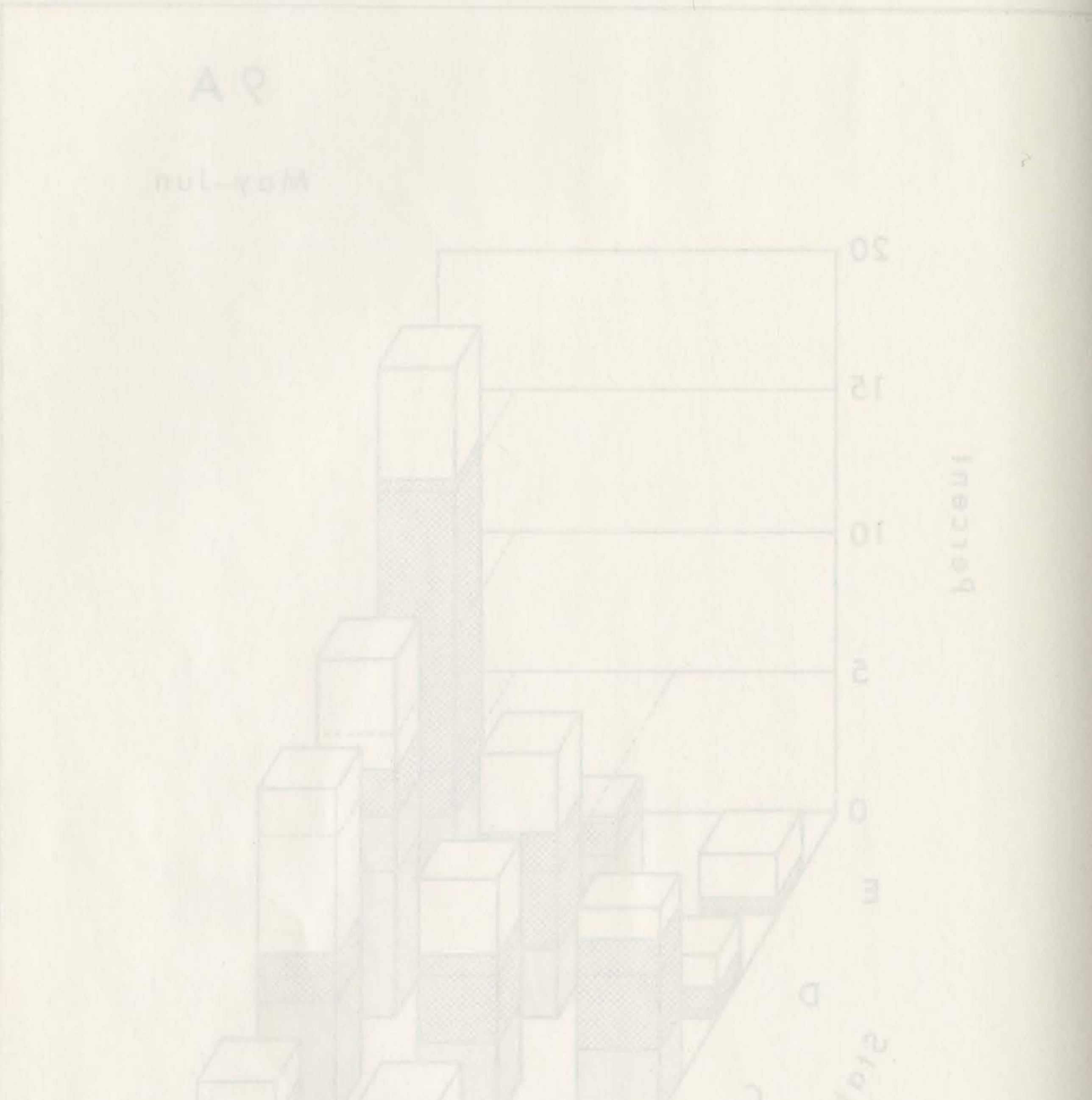
D. November and December, 1963.

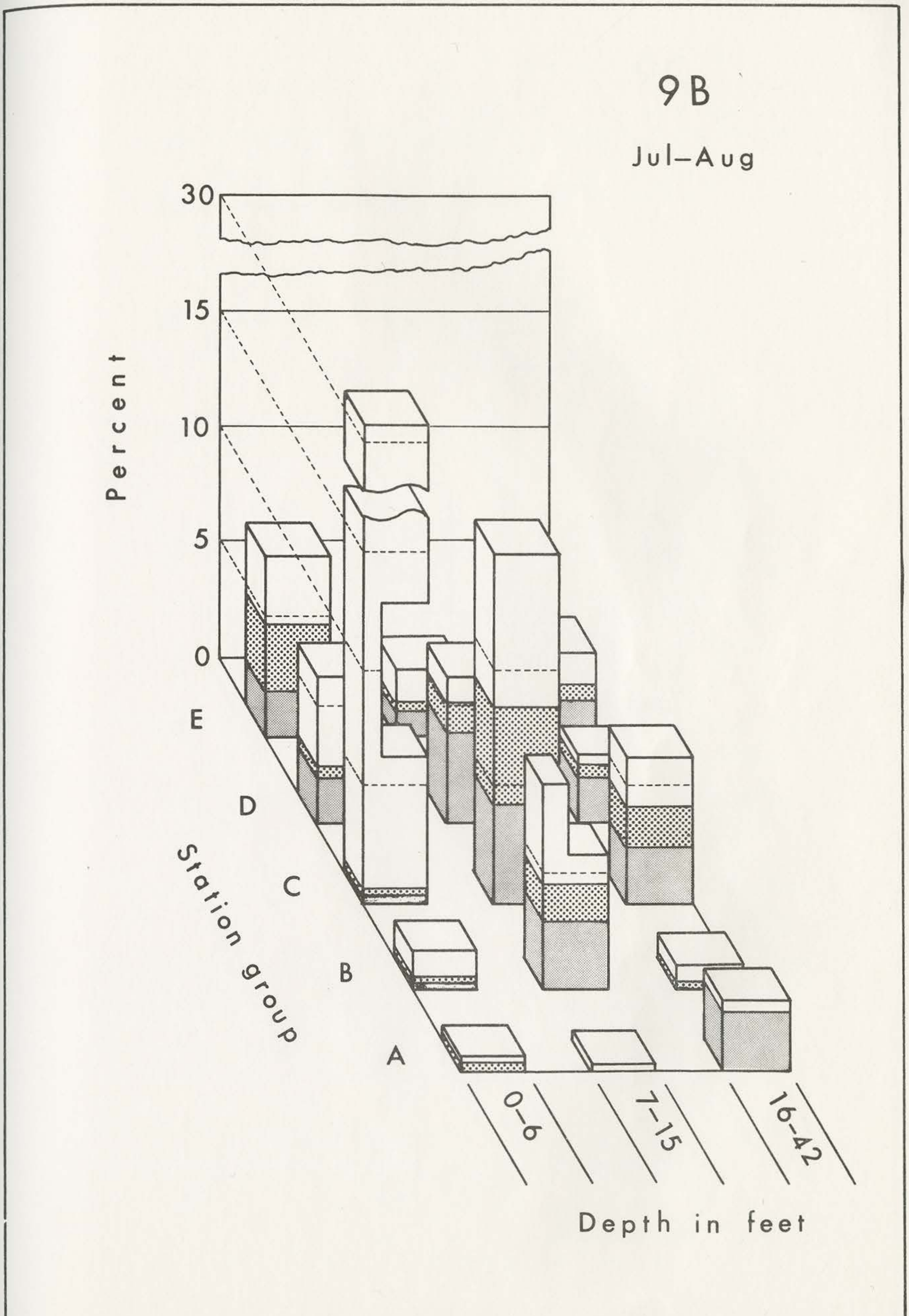
E. January and February, 1964.

F. March and April, 1964.



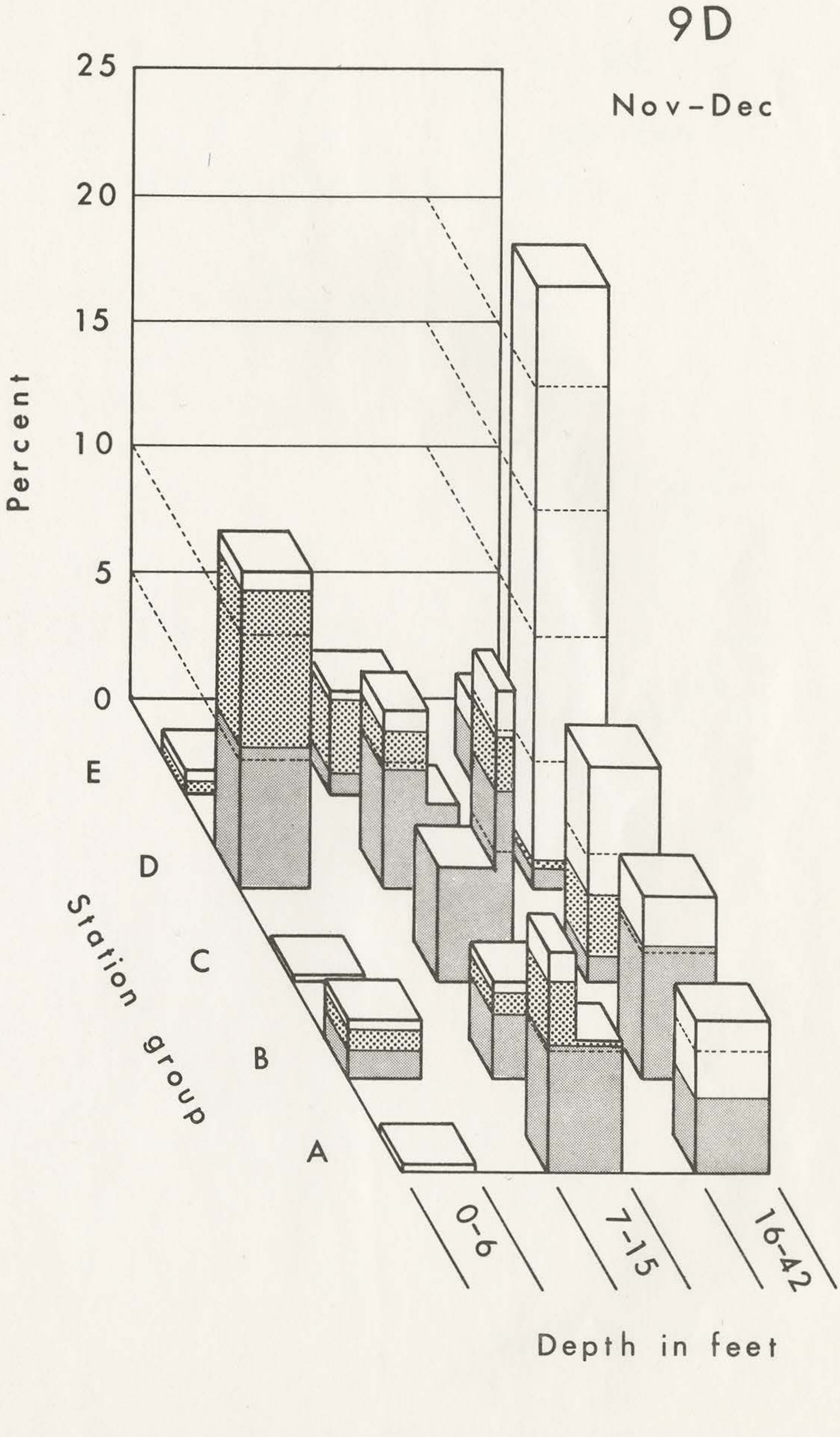
9 A
May–Jun
Percent
20
15
10
5
0
E
D
C
B
A
Station group
0–6
7–15
16–42
Depth in feet
–Other fishes
–Spot
–Croaker

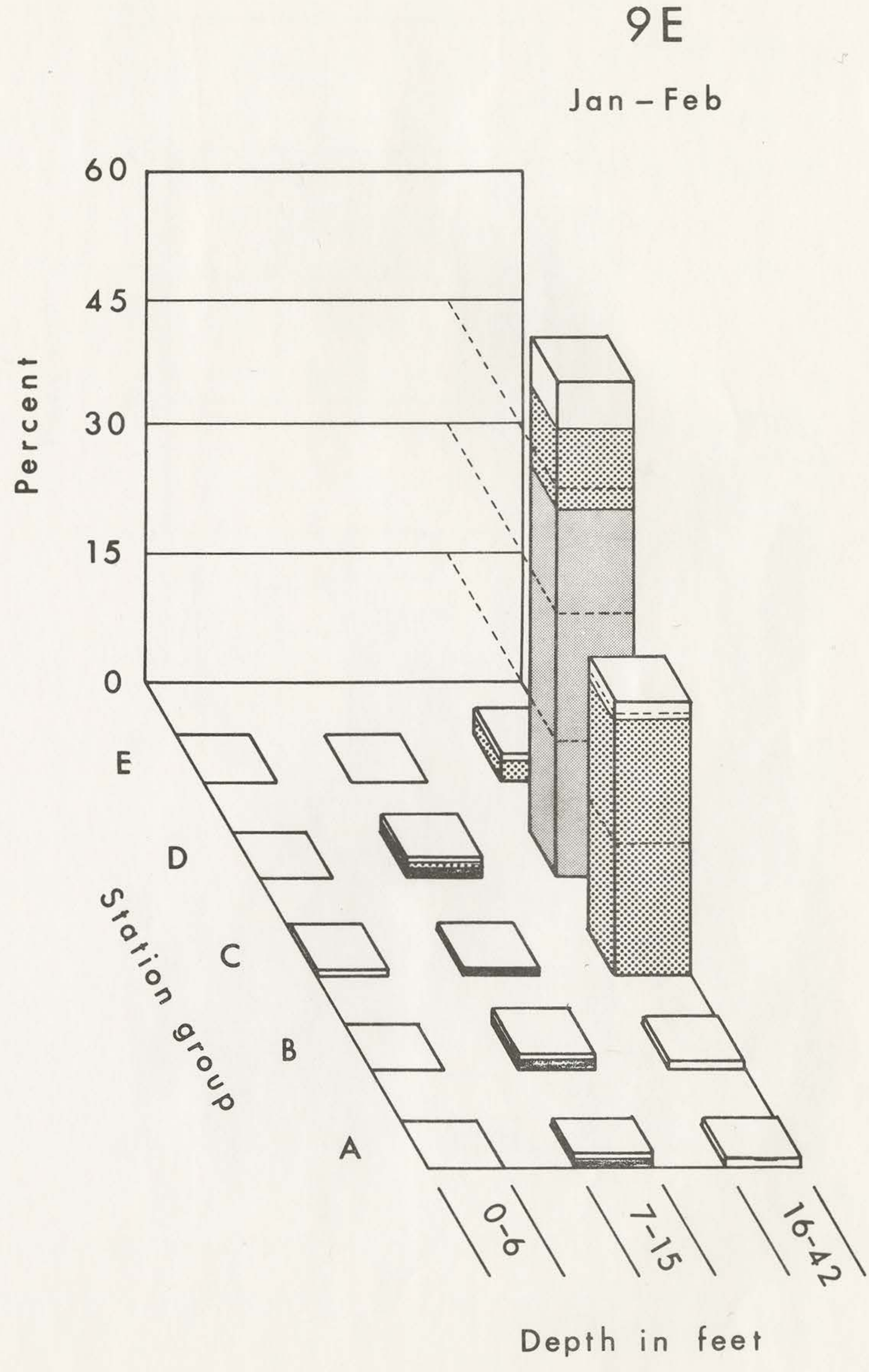

9A
May-Jun
20
15
10
5
0
percent
E
D
C
B
A
station group
16-42
7-15
0-6
Depth in feet
—Other fishes
—Spot
—Croaker

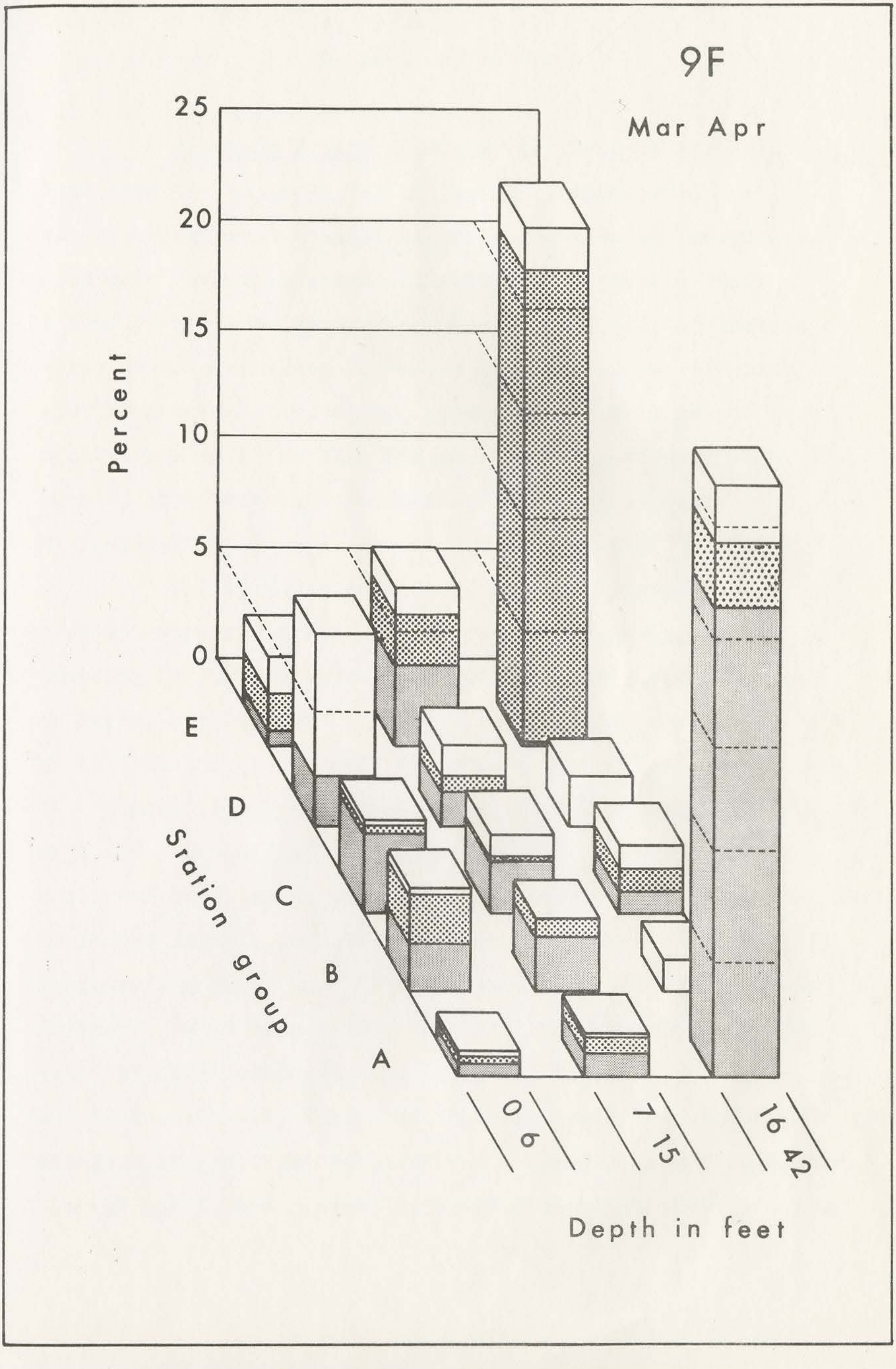


9B
Jul–Aug
30
15
10
5
0
Percent
E
D
C
B
A
Station group
0–6
7–15
16–42
Depth in feet


9C
Oct.
Percent
20
15
10
5
0
E
D
C
B
A
Station group
0-6
7-15
16-42
Depth in feet


9D
Nov-Dec
Percent
25
20
15
10
5
0
Station group
E
D
C
B
A
0-6
7-15
16-42
Depth in feet


9E
Jan – Feb
60
45
30
15
0
Percent
E
D
C
B
A
Station group
0-6
7-15
16-42
Depth in feet


9F
Mar Apr
25
20
15
10
5
0
Percent
E
D
C
B
A
Sration group
0 6
7 15
16 42
Depth in feet

BIOLOGY OF THE SPOT

Spawning Period: Because the mesh of the otter trawl was too large to retain larval or postlarval spot, the spawning period cannot be estimated with any certainty. John Bell (personal communication) caught juvenile spot (about 25 mm) from January through March, 1966, in shallow marsh seining stations in Mobile Bay. Since no very small spot were taken after March, spawning may be estimated to occurr from no later than December at least through February. Data on file show that juveniles (20-40 mm) appeared in Mississippi Sound trawl catches in March, 1966.

The spawning periods of spot and croaker appear to overlap, with the spawning peak of spot occurring last. Spawning in Texas extends from late December until the last of March, with a peak in January and February (Pearson, 1929). He collected spot as small as 12 mm from December 31 to March 30. Gunter (1945) collected spot with well developed roe and milt off Texas in early November and late January, and collected spent males and females in late January. Hoese (1965) collected larval spot off the Texas coast at Port Aransas in February and March, and took specimens smaller than 7 mm in February. Sundararaj (1960) reported that young were first taken in Lake Pontchartrain, Louisiana in January. Springer a and Woodburn (1960, Table 13) show that spot less than 22 mm, standard length, were taken in the Tampa Bay area from January through April, and present data which suggests that spawning begins in late December or early January, and continues through March. Dawson (1958) reported that ripe or ripening fish were taken in South Carolina during October, December, and February, and spent fish were observed in February.

Welsh and Breder (1923) noted that postlarval spot have been taken in Chesapeake Bay, and in Florida waters in St. Vincents Sound, St. Josephs Bay, and Charlotte Harbor from January to April. They conclude from this that the spawning period appears to be the same in both Atlantic and Gulf waters. Hildebrand and Cable (1930) estimated that spawning, at Beaufort, may take place as early as November, but the principal spawning months are December and January, with reduced spawning activity in February. However, they collected spot of 14 mm or less from December through May, and as it seems unlikely that a 14 mm spot would be three months old, this suggests that spawning, however reduced, may have extended at least into late March.

Spawning Locality: Spawning takes place when spot reach two years of age, according to Pearson (1929), Dawson (1958), Hildebrand and Cable (1930), and others. Spot reach a length of about 200 mm at the age of two, as reported by Sundararaj (1960), and the above mentioned authors. During the present investigation this size (and age) group is primarily concentrated in waters in excess of 15 fathoms in January and February (Figure 10) so spawning apparently takes place well offshore in the northeastern Gulf of Mexico. Off Mobile Bay, a depth of 15 fathoms occurs about 15 miles offshore.

Age, Growth, and Movement: Too few older fish were caught to accurately depict the sizes of both age groups of spot in Mobile Bay. While some overlap in age groups may occur, the catch of fish estimated to be in excess of one or two years of age was too small to show length modes. Inshore data is primarily limited to 0-class fish.

Monthly frequency distributions of total length are given in Table 9. The modal size of the 0 age class in May and June is probably lower than the data indicate owing to mesh selection of the larger members of the 0 age class. This bias is reduced as the year progresses through increasing size of individuals of the 0 age class. The October samples which show a majority of fish at 110-129 mm, are probably fully representative of the group. Among larger fish however, the problem of gear selectivity may again occur. Hoese (personal communication) reports that diurnal trawl studies in Texas Bays show spot were taken in equal abundance during hours of darkness and daylight when samples were taken in murky water, while night catches of spot greatly exceeded day catches when the water was clear. He attributes this phenomenon to net avoidance by larger spot, and since he was using a 20-foot trawl, it is quite possible that avoidance of the smaller trawl used in the survey was of importance even in the usually turbid waters of Mobile Bay.

During December and January, an apparent reduction occurred in the modal size of the 0 age class. This may be due to emigration of the larger individuals of the 0 age class.

Small fish, presumably of the 0 class, are reported from Chesapeake Bay for December and January by Hildebrand and Schroeder (1928). The average size of these fish was notably smaller than that of specimens of the same year class taken in October and November. The authors came to the tentative conclusion that the fish taken in Chesapeake Bay during the winter probably were the 'runts' of the last spawning season which had remained in the bay, while the larger representatives of the same year class had departed. This contention was strongly supported by the behavior of spots at Beaufort (Hildebrand and Cable, 1930).

Dawson (1958) reported minimal winter growth of inshore spots in South Carolina, although he did not report offshore migration by 0-age-class fish. Sundararaj (1960, figure 17) shows a decrease in size from October, 1953 to March, 1954, in Lake Pontchartrain, which probably indicates a migration of larger 0-age fish from the lake. Mobile Bay data support the hypothesis of emigration of 0-age fish during the winter months. The mode drops from 125 mm in November to 105 mm in January, with growth apparently taking place in March and April. This winter emigration is even more apparent in Figure 10, which shows an influx of small fish into nearshore areas of the Gulf in November and December, with the number assuming major proportions in January and February.

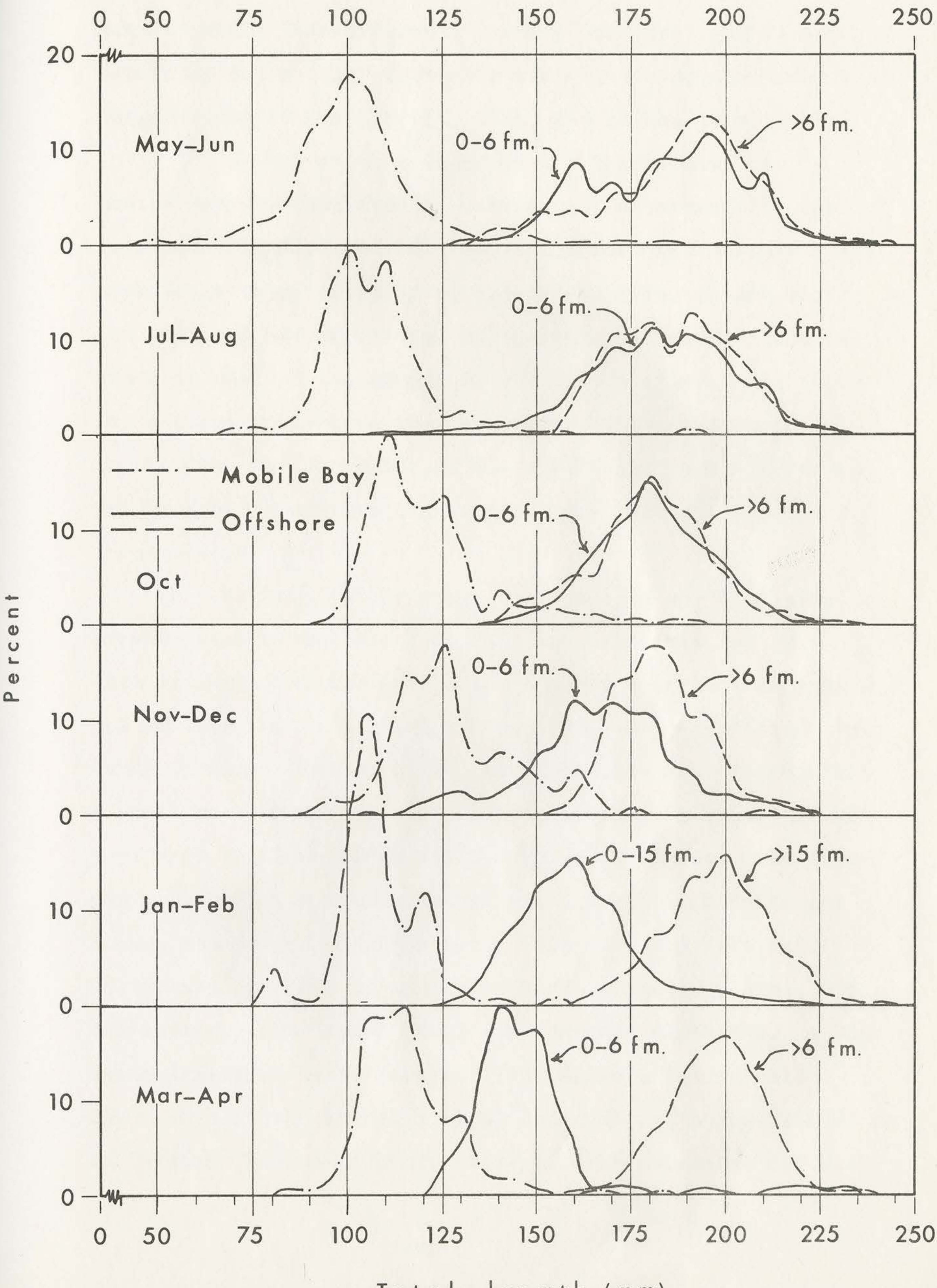
Table 9. Length frequency distributions of spot in Mobile Bay

Total length mm	May	Jun	Jul	Aug[1]	Oct	Nov	Dec	Jan	Feb[2]	Mar	Apr
45	1										1
50	2	1									
55	5	0	1								
60	7	5	0								
65	10	1	0								
70	22	7	3								1
75	26	28	3					1			
80	38	30	1	1				35			
85	68	75	7	0				7		1	
90	126	166	16	2			1	0	1	2	1
95	143	181	54	12	2	1	3	37	0	9	1
100	137	296	66	8	14	1	2	179	1	22	16
105	67	335	39	18	39	1	6	266	0	99	27
110	23	246	52	16	63	6	11	123	0	111	26
115	16	128	27	12	42	7	30	67	3	109	17
120	5	93	14	7	38	9	23	104	0	58	17
125	1	53	4	3	42	17	25	21	1	30	23
130	6	23	6	3	23	5	16	14	0	36	21
135	6	14	1	3	7	4	8	0		2	16
140	17	3	4		12	9	6	1		4	9
145	19	5	1		6	7	6	7		5	6
150	3	0			6	2	7	0			6
155	0	0			5	1	5	0			
160	1	0			3	4	7	7			
165	1	0			4	2	3			1	1
170		4			1		0				
175		0			3		1				
180		4			0					1	
185					1						
190					1						
195											
200			1				1				
205											
210											
215											
220	1										

1 No samples taken in September

2 Channel stations not sampled in February

FIGURE 10. Bi-monthly length-frequency percentages of spot in Mobile Bay, and offshore in the northern Gulf of Mexico. (Offshore curves computed from data provided by Charles M. Roithmayr, personal communication).



0
50
75
100
125
150
175
200
225
250
20
10
0
May–Jun
0–6 fm.
>6 fm.
Jul–Aug
Mobile Bay
Offshore
Oct
Nov–Dec
Jan–Feb
0–15 fm.
>15 fm.
Mar–Apr
Percent
Total length (mm)

Many of these fish apparently remain offshore, and do not return to the estuary after the winter, as shown by the length modes in March-April, 1964, and in May-June, 1963.

Growth among members of the 0 age class in Mobile Bay was difficult to determine. An average of the fish found inshore and offshore in January and February provides a rough estimate of 135-140 mm total length for the size reached at the age of one year. This estimate is close to that of Sundararaj (1960) of 142-143 mm, and also falls close to that of several other authors for varying localities. An exception is Chesapeake Bay, where Welsh and Breder (1923) report a lesser size, and Pacheco (1962) a greater size.

Pacheco (1962) suggests that spot may have varying growth rates at different localities within the estuary. This is suggested for Mobile Bay from data on file (Figure 11) collected by using a trawl with a 1/4" bar mesh cod end liner which retained smaller fish. Marsh samples were taken with a small mesh bag seine. It is noteworthy that young of the year were first taken in marsh samples in January, while they did not appear in trawl catches until March in Mississippi Sound, and April in Mobile Bay. This probably is a result of outward movement of spot from marsh areas into the bay in the spring. The figure shows considerable difference in modes (mean length in marsh samples) from different localities. One-year-old fish in Mississippi Sound showed a mode at 140 mm in February, which is quite close to that estimated for fish at the end of their first year in the 1963-64 survey. Growth rates are obscured somewhat by the prolonged spawning period.

Monthly growth increments for various localities (Table 10) show Mobile Bay growth rates to be roughly comparable with those of Tampa Bay, Cedar Bay, Lake Pontchartrain, and North Carolina.

Members of the I age class were taken from the bay in rather small numbers throughout the year. Although avoidance of the collecting gear might partially account for the small portion of that age group taken, it is apparent that a sizeable portion of the I age class was present offshore throughout the year, instead of staying in the bay until approaching the age of two, as reported by some authors for the South Atlantic and Gulf of Mexico. Table 9 shows a slight mode at 140-149 mm in May and June, with a small number of fish, which probably exceeded one year of age, being taken throughout the year. However, these were probably the smaller members of the I age class which did not leave the bay during the winter, and not representative of that age group.

Three age groups appear in Figure 10 for May-June. The 0 age class and some older spot are found within the bay, with the I and II age classes being dominant in the offshore catch. The offshore percentage of two-year-old fish is greater than that of the one year olds, although

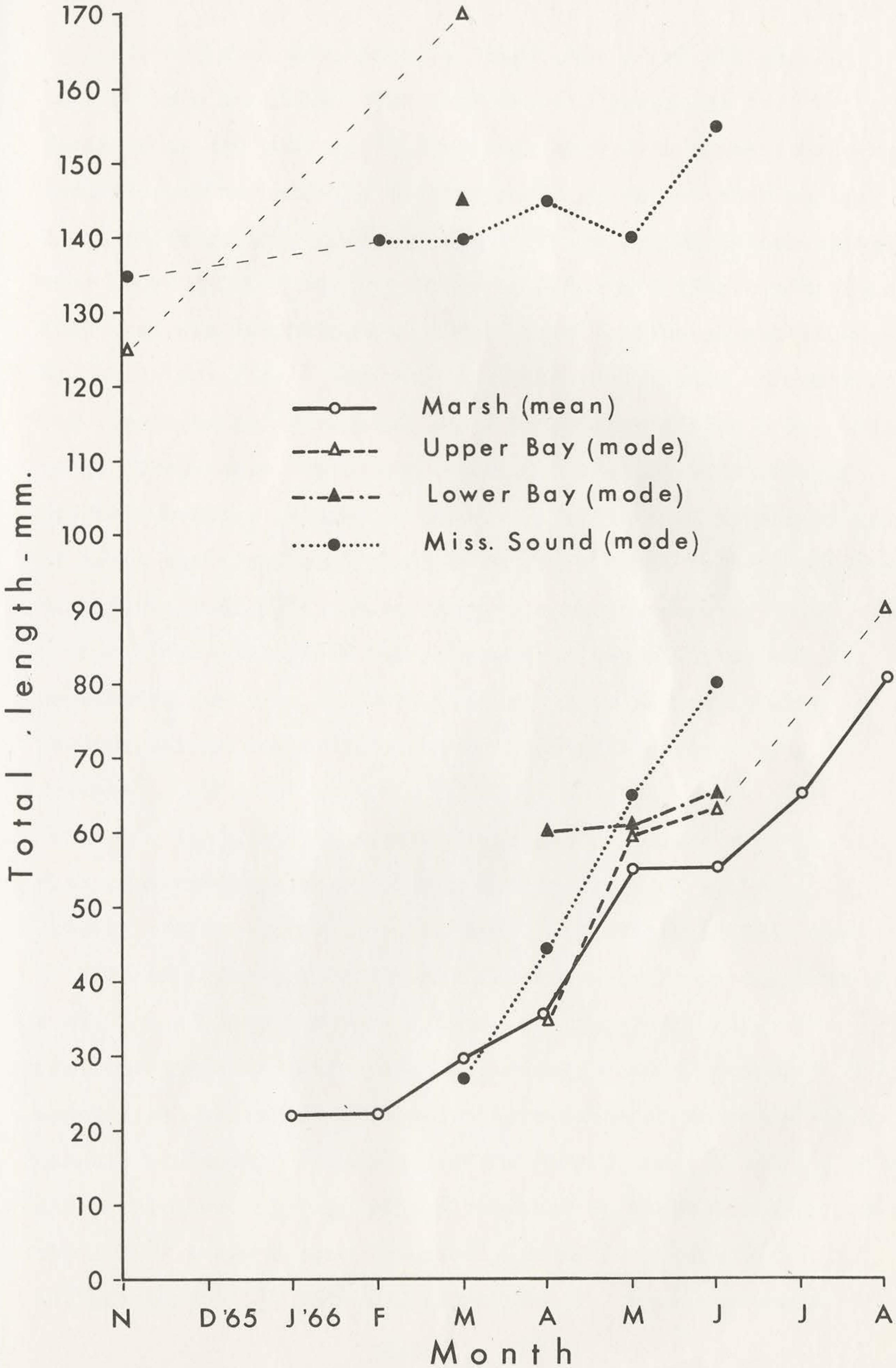
Table 10. Mean total lengths of "0" age class of spot from different localities (modified from Springer and Woodburn, 1960, Table 14)

	Pearson (1929)	Sundararaj (1960)[1]	Nelson	Bell	Kilby (1955)	Springer & Woodburn (1960)	Hildebrand & Cable (1930)
	Texas	Lake Pontchartrain	Mobile Bay mode	Mobile Bay	Cedar Key	Tampa Bay all stations	North Carolina
Dec	----	---	---	--	--	-----	3.7
Jan	----	20	---	22	20	27.3	12.6
Jan-Feb	26.7	---	---	--	--	-----	-----
Feb	----	20	---	22	36	35.8	18.5
Feb-Mar	31.8	---	---	--	--	-----	-----
Mar	----	35	---	29	48	36.4	20.3
Mar-Apr	55.4	---	---	--	--	-----	-----
Apr	----	60	---	36	60	46.5	29.8
Apr-May	62.6	---	---	--	--	-----	-----
May	----	65	95	55	66	58.1	45.8
Jun	----	90	105	56	97	76.1	57.7
Jul	----	120	100	65	--	97.5	81.4
Aug	----	105	105	82	--	79.6	104.6
Sep	----	120	---	--	--	80.3	115.5
Oct	----	130	110	--	--	90.4	129.5
Nov	----	135	125	--	--	101.5	139.3
Dec	----	140	115	--	--	113.1	-----

1 Mode estimated from Sundararaj (1960, Figure 17 for 1954)

2 Bell, personal communication

FIGURE 11. Lengths of spot in various localities in Mobile Bay, and Mississippi Sound from November, 1965 to April, 1966.



170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
Total length - mm.
Marsh (mean)
Upper Bay (mode)
Lower Bay (mode)
Miss. Sound (mode)
N
D'65
J'66
F
M
A
M
J
J
A
Month

one-year-old fish constitute a large portion of the catch in 6 fathoms and less. The one-year-old group can be followed as the mode shifts to the right, with a corresponding reduction in the mode of fish approaching three years of age. This indicates that one-year-old fish are becoming increasingly more abundant, and larger, while two-year-old fish are becoming less dominant and numerous in the catch. Although not shown by Mobile Bay data, there was apparent recruitment of one-year-old fish from bay and sound areas into the offshore area, where length frequencies were very similar for shallow and deeper offshore waters. Figure 10 shows recruitment of larger members of the 0 age class into shallow offshore areas in November and December. Shallow offshore samples were composed of both 0- and I-age-class fish, which explains the shift of the population curve to the left, while I-age-class fish were predominant in the offshore catch in depths greater than 6 fathoms.

The almost complete departure of larger 0-age-class fish (now one year of age) from Mobile Bay took place in January and February. They became concentrated in less than 15 fathoms offshore. While the nearshore catch is composed of a mixture of fish that are now one and two years old, the major portion of the offshore catch (in deeper than 15 fathoms) appears to consist of fish which have reached two years of age and are presumably spawning for the first time. A fairly clear delineation between age groups is noted in March and April, with the I and II age classes primarily found in waters less than and greater than 6 fathoms, respectively. Spot apparently disperse throughout the nearshore and offshore areas during the early summer and fall as shown by the length frequencies during the preceding May to October period. The reduction in the mode and range of the January-February nearshore fish in March-April is probably due to lack of two-year-old fish nearshore, which were previously present up to 15 fathoms, combined with further recruitment from local estuaries.

The length mode of the fish at the end of their second year of life in January-February was 200 mm, which agrees closely with the estimates of Sundararaj (1962) of 200.1 mm and 212 mm as determined from scale radius and otolith radius, respectively, for Lake Pontchartrain. The range of approximately 160 mm to 235 mm is in fairly close agreement with that of other authors, as shown by Dawson (1958, Table 7). The rather wide range may be accounted for by the presence of some large one-year-old fish in the deeper area, along with a few fish which had reached three years of age.

Abundance and Seasonal Distribution: The spot was the second most abundant fish taken, appearing in 67 percent of all trawl samples. Of 16,043 fishes taken spot were 31 percent by number and 29 percent by weight, ranking second to the croaker in Mobile Bay.

Gunter (1945) reports the spot to rank sixth in abundance in trawl hauls in Texas bays and in the Gulf. Perret (1966) ranks the spot fifth in vertebrate abundance in trawl catches in Vermillion Bay, Louisiana. Rounsefell

(1964) found the spot to be the most common fish taken in trawl hauls in the area south and west of Lake Borgne, Louisiana. However, Figure 2 in his paper shows that a majority of sampling stations were either in shallow marsh areas, or in bayous winding through the marsh, not in open bays. His data show spot in low relative abundance in limited sampling in Lake Borgne and Breton Sound. Sykes and Finucane (1966) report juvenile spot very abundant in Tampa Bay; major concentrations were in Old Tampa Bay and lower portions of the estuary. Gunter and Hall (1965) in trawl catches from the Calooshatches estuary, show spot ranking third in abundance. Spot, Roithmayr (1965a) comprise by weight, 5 percent of the commercial bottomfish catch west of the Mississippi River Delta, compared to 13 percent east of the delta. Spot rank second in abundance in the fishery.

Spot show a general increase in abundance from west to east along the northern Gulf of Mexico. This also is true in terms of abundance relative to the croaker. In trawl samples, Gunter (1945) shows a croaker to spot ratio of approximately 15 to 1 in Texas, Perret (1966) 8.9 to 1 in western Louisiana, the author 1.5 to 1 in Mobile Bay, and Gunter and Hall (1965) 1 to 3 in the Caloosahatchee estuary. The decrease in the percentage of croaker caught in the commercial bottomfish industry from west of the Mississippi River delta to east of the delta is coupled with an increase in the percentage of spot from west to east. The total bottomfish catch per unit of effort (Roithmayr, 1965a) is greater in the eastern Gulf than in the west, with the corresponding catch of spot increasing, while the catch per unit of effort of croaker remained fairly even from west to east; croaker density probably remaining high as far east as Mobile Bay, with a west to east increase in spot abundance of least that far. Although, a decrease in abundance of spot may occur farther east, it is apparently not as sharp as that of croaker.

The bi-monthly catch of spot per tow by number and by weight, and its percent of the total vertebrate catch for Mobile Bay is shown in Table 11. Offshore percentages are given for comparison with inshore data. An average of 18.8 fish per tow was taken during the survey. Catch of spot exceeded that of croaker in May and June, when spots were taken in 89 percent of the trawl samples. Various authors have shown the peak inshore abundance of spot to occur in spring and early summer, but low spring and summer levels of abundance were found by Hildebrand and Cable (1930) at Beaufort, and Dawson (1958) in South Carolina.

The tremendous reduction in catch in July and August is unexplained. Spots may have gone into shallow waters, but the percent biomass (Figure 9b) in shallow areas does not comfirm that theory. That they might have migrated offshore during July and August is not supported by Figure 10, which shows no large influx of young of the year into the offshore catch.

Table 11. Bi-monthly catch per tow and percentage of spot in Mobile Bay trawl samples, and percentage of offshore catch east of the Mississippi River Delta May, 1963 - April, 1964 [1]

	Mobile Bay					Offshore
Months	Frequency of occurrence in samples	Number per tow	Total catch by number	Catch per tow	Catch by weight	Total weight
	Percent		Percent	grams	Percent	Percent
May-Jun	89.1	37.9	43.91	619.5	36.45	15.34
Jul-Aug	70.4	8.6	18.44	140.9	15.26	14.88
Sep-Oct	81.2	9.8	14.96	261.6	20.77	10.92
Nov-Dec	60.5	6.5	15.56	199.6	27.06	10.49
Jan-Feb	40.0	27.4	41.14	425.7	36.37	37.28
Mar-Apr	52.0	12.4	25.03	269.8	25.67	11.39
Annual Mean	67.3	18.8	30.65	342.6	28.91	16.22

[1] Offshore data provided by Roithmayr, personal communication

Catch per unit of effort remained low through November and December, with the average weight per fish rising to 30.7 grams from 16.3 grams in May and June. The low catch in November and December probably results from an offshore movement during the late fall as shown by Figure 10.

The apparent high catch per unit of effort in January and February is more than likely due to the heavy concentration of fish in the ship channel. As discussed in the section on croakers, the channel was over-sampled in relation to its area when compared to the rest of the bay. Concentration of fish in a heavily sampled area would give an erroneous impression as to the population size throughout the bay, based on catch per unit of effort. The concentration is shown by an increase in number and weight per tow, combined with a decrease to only 40 percent of Mobile Bay trawl samples containing spots during January and February. The reduction in average weight per fish to 15.5 grams adds support to the hypothesis of offshore movement of larger juveniles as shown in Figure 10, and discussed in the section on age, growth, and movement. The high percentage of spot to other species in the offshore catch appears to result from this offshore movement. The catch per unit of effort in the bay in March and April shows abundance decreasing outward from the channel towards the shallower areas of the bay, combined with a reduction in the total number of fish taken, and an increase in the percent of occurrence in trawl samples.

Bi-monthly distribution of spots based on catch per unit of effort, by weight, is shown in Figure 11.

While the "biopleths" are somewhat empirical, the figure serves to show major areas of concentration and distribution of the population throughout the year.

The general distributional pattern of young-of-the-year spots in Mobile Bay is a dispersal into nearshore areas in the spring, followed by heavier concentrations in mid-and lower bay areas throughout the summer and fall. Spots are found almost exclusively in the ship channel and the deep area at the mouth of the bay in the coldest portion of the year. Concentrations of spots which are older and larger occur near the mouth and in lower portions of the bay in the spring and fall. Of special interest is the middle bay area of low density which was evident for several months.

The low mid-summer abundance has been discussed above. The small numbers of the population that were taken were caught chiefly in the middle of the bay. Spots were taken in 70 percent of all mid-summer trawl samples, despite the low density.

The concentration of spot in the ship channel in January and February is even more striking than that of croaker. While a few fish were taken outside the channel, they were in deep water to the east, and were in the area of greatest influence of Gulf water except for the lower channel itself. Approximately 98 percent of the total catch, by weight, of spots was taken from the area of concentration shown in Figure 11.

Dispersal from the ship channel in the spring was to nearshore areas, with fairly high density of young fish in shallow waters away from the bay entrance.

Relation of Spot to Salinity: Spots were taken in a salinity of 0.0 o/oo to 33.9 o/oo during the survey. However, only one spot was taken at 0.0 o/oo, and none were taken below 0.4 o/oo in fourteen trawl hauls during March and April. Gunter (1945) reports spots taken in a salinity range of 2.0 o/oo to 36.7 o/oo in Texas. Springer and Woodburn (1960) captured spot in a salinity range of 5.0 o/oo to 34.2 o/oo in Tampa Bay. Gunter and Hall (1965) report spots taken in the Caloosahatchee estuary at a low salinity range of 0.12 - 0.72 o/oo.

In Mobile Bay spots were more abundant at higher salinities. Overall data shows 23.8 spot per tow at salinities of 14.0 o/oo and greater, compared to 14.3 per tow at lower salinities. In salinities of 27.0 o/oo and greater, 47.5 spot were taken per unit of effort. Spot showed an increase in catch per unit of effort in all seasons with higher salinities (Figure 12), except for July and August, when more were taken at moderate salinities (5.0-13.9 o/oo), and November and December, when the catches were erratic. Spots were never abundant at very low salinities, with the catch per unit of effort in March and April at 2.0 - 4.9 o/oo being three times that at 0.0 - 1.9 o/oo. Thirty-three samples were taken in the lowest salinity grouping. Dawson (1958) points out that postlarval and juvenile spot are abundant in waters of lower salinity. Samples from Mobile Bay were older young of the year, and it is assumed that postlarval and young juvenile spot would be found in lower salinities.

Less has been written about the relation of size to salinity for spot than for the croaker, but results are no less diverse. Reid and Hoese (1958) theorize that factors other than salinity are responsible for the size distribution of spot in East Bay, Texas. Dawson (1958) reports spots under three inches were most common at low salinity stations, but merely calls this an "apparent" low salinity preference, and lists bottom type and food availability as possible influencing factors. Springer and Woodburn (1960) state that spot movement from a low salinity area in Tampa Bay might have been triggered by a size increase. Darnell (1958) shows less of a gradation in the different food types preferred by spot than for croaker, and the spot consequently may not need to shift localities within a bay-system to as great an extent as does the croaker, thereby producing less of a size-locality cline within a system, if food is the predominate factor in size distribution.

Length modes and ranges of spot by salinity categories (Figure 13) show generally a positive size-salinity relation from May and June to October. The relationship during May and June is confusing, as the modal size is less in intermediate salinities (9.0 - 20.0 o/oo). All modes shown are for young of the year, since one-year-old fish were caught too infrequently to furnish sufficiently large samples. The relationiis fairly clear in July and August, but obscured in October. The modes are the same for different salinities in November and

FIGURE 12. Bi-monthly areal distribution of spot in Mobile Bay, based on catch per unit of effort.

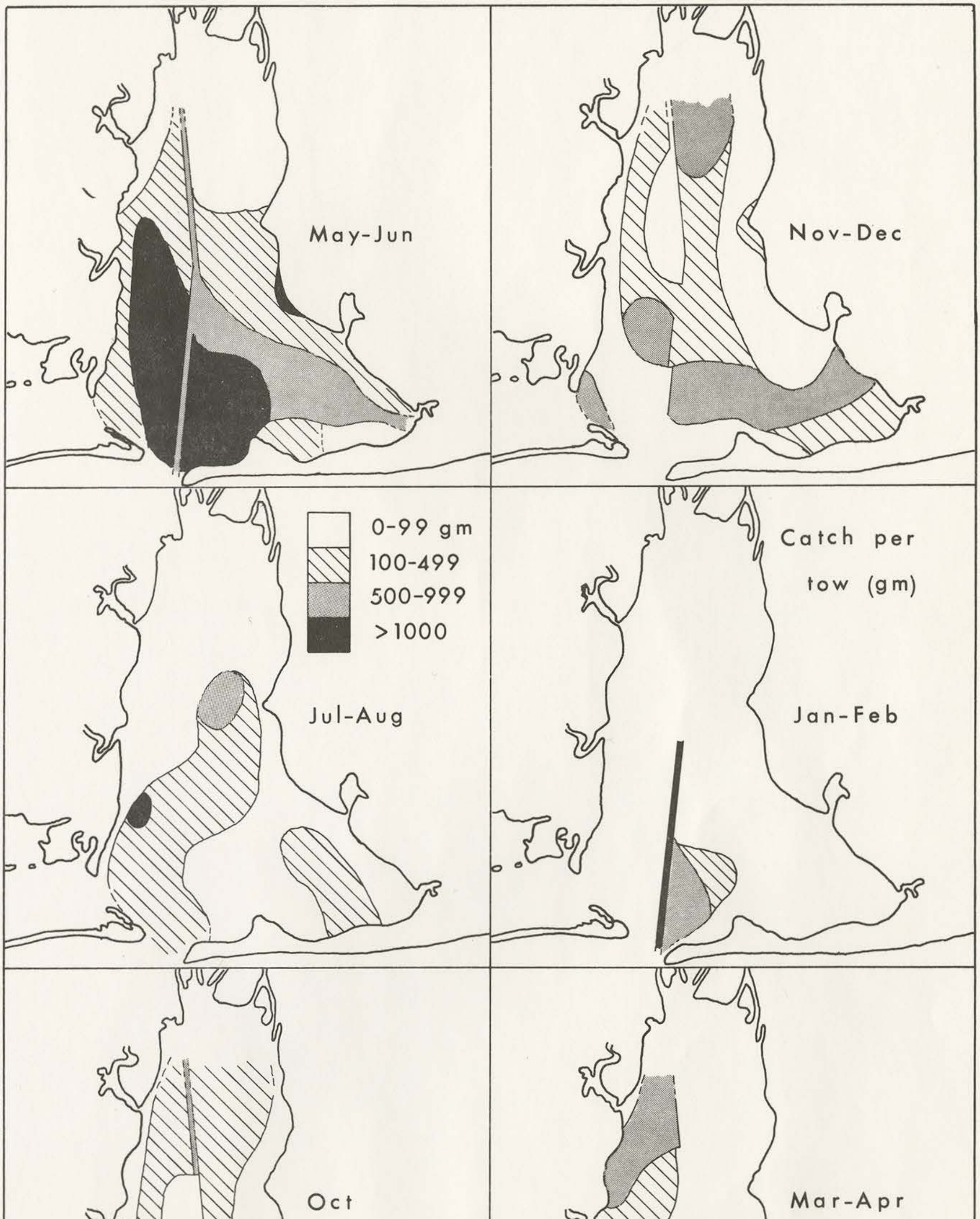
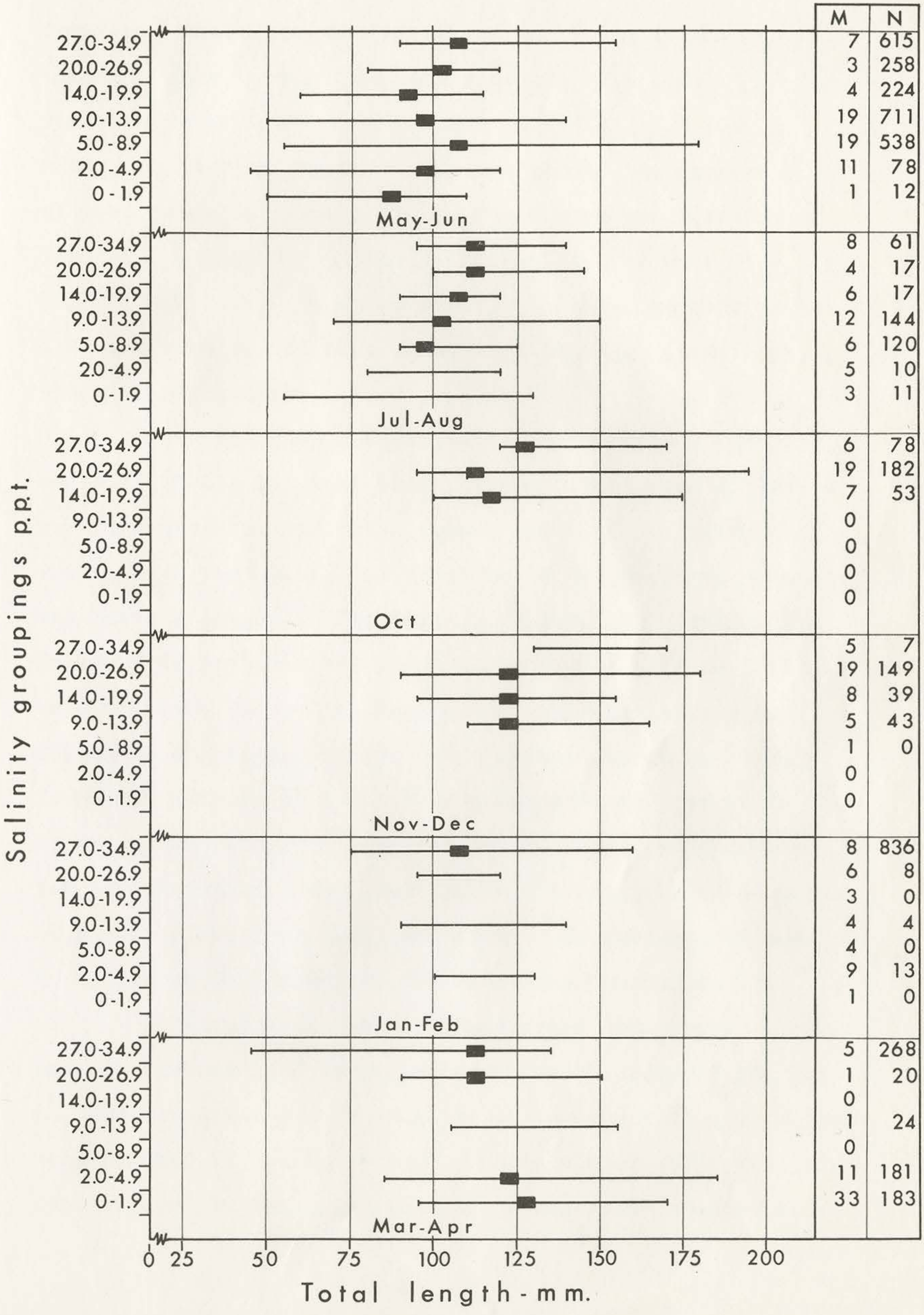

May-Jun
Nov-Dec
0-99 gm
100-499
500-999
>1000
Catch per
tow (gm)
Jul-Aug
Jan-Feb
Oct
Mar-Apr

FIGURE 13. Bi-monthly length ranges and modes of Mobile Bay spot by salinity catagories. (Number of samples) (Number of specimens).


M
N
27.0-34.9
20.0-26.9
14.0-19.9
9.0-13.9
5.0-8.9
2.0-4.9
0-1.9
May-Jun
Jul-Aug
Oct
Nov-Dec
Jan-Feb
Mar-Apr
Salinity groupings p.p.t.
0 25 50 75 100 125 150 175 200
Total length - mm.
7 615
3 258
4 224
19 711
19 538
11 78
1 12
8 61
4 17
6 17
12 144
6 120
5 10
3 11
6 78
19 182
7 53
0
0
0
0
5 7
19 149
8 39
5 43
1 0
0
0
8 836
6 8
3 0
4 4
4 0
9 13
1 0
5 268
1 20
0
1 24
0
11 181
33 183

December, resembling the situation occurring in the croaker, where young fish show somewhat of a size relation to salinity in the summer and fall, but the winter population shows no such relation. The numbers of spot taken in January and February were adequate to determine modes only in the ship channel, the area of highest salinity. In March and April, there appears to be a slight reversal of modal size with increasing salinity, which is unexplained.

Correlation coefficients between fish length and salinity (Table 12) were inconclusive. They tend to show a positive correlation in the summer and fall, as indicated above, with practically no relation in November and December, and March and April. The high coefficient for January and February is probably erroneous since practically no fish were taken at low salinities; almost all specimens were caught in the high salinity ship channel, which would confound the effects of salinity and temperature. As with croakers, coefficients for spot length versus salinity and for length versus depth form almost a straight line relationship when plotted against each other. No attempt was made to determine the effect of the variables independently.

<u>Relation of Spot to Temperature and Depth</u>: Spots were distributed throughout moderate depth areas of the bay in summer and autumn. During the spring major concentrations were located in shallow waters, and in winter, they were concentrated in the ship channel. Temperature changes are

probably the direct cause of seasonal movement of spot into different depths within the bay. Because of this, and the difficulty of considering one of the factors separately, temperature and depth are discussed here in terms of the interrelationships in regards to the movement and abundance of the spot.

Spots were taken at a temperature of 6.3°C in Mobile Bay, but only 8 spot were collected in 2 samples out of 9 taken at temperatures of 9°C or less, while spot appeared in 7 of 12 samples between 9°C and 10°C. The minimum threshold temperature for spot is rather low. Hildebrand and Cable (1930) found numb young of the year at 5°C, but no mortalities. Dawson estimates the lower limit to be 4.0 to 5.0°C. He reports that spot have been trawled in South Carolina in temperature as low as 6°C, but feels that the abundance increases above 10°C. Spot are also reported at higher than normal temperatures along the Gulf and Atlantic coasts, but little information is available as to the upper temperature limit. Spot were taken at a temperature of 31.0°C in Mobile Bay, the highest recorded in the survey.

Relation of growth rate of spot to temperature is confusing because salinity, depth, and temperature are somewhat interrelated, and the individual effect (if any) of each is difficult to determine. Mobile Bay growth (Figure 10, Table 9) appears to be fairly rapid through months of warm temperature, and to continue at a reduced rate during the

Table 12. Correlation coefficients between individual lengths of spot and salinity, temperature, and depth in bi-monthly time periods, May, 1963 - April, 1964

Months	Number of Specimens	Correlation Coefficients Salinity	Temperature	Depth
May-Jun	2,449	.267	.021	.058
Jul-Aug	385	.066	-.103	.054
Oct	312	.336	.265	.265
Nov-Dec	237	.015	.007	-.007
Jan-Feb	875	.449	.248	.508
Mar-Apr	679	-.001	-.195	-.057

winter (taking into consideration the portion of the 0 age class which migrated offshore). Welsh and Breder (1923), Dawson (1958), Pacheco (1962), and Sundararaj (1960) either state, or show data which indicates slow growth of spot during the coldest months. Influx of postlarvae over a period of three to four months, and offshore movement of larger fish during the winter may well cause an obscuring of actual growth rates. Several authors cite fast growth of 0-age spot during the spring and summer along the Atlantic and Gulf coasts.

Correlation coefficients for the relation of individual length of spot to temperature are shown in Table 12 for bi-monthly groups. No significant correlations were found, although inferences can be made. The negative coefficient for July and August tends to show that larger fish frequent the shallows during the warmest months. The moderate positive coefficient for October indicates the concentration of larger individuals around the mouth of the bay in the influence of the Gulf water mass. Bi-monthly correlation coefficients between individual lengths and depth (Table 12) show a high coefficient for January and February. This has been discussed in the section on salinity, and is probably a result of very few specimens being taken outside the ship channel during the period. This limited range of depth and temperature reduces the significance of the correlation. The moderate coefficient for October is probably due to the concentration of larger young of the year, and some one-year-old fish in deep areas inside the mouth of the bay. Negative coefficients for depth and temperature in March and April suggest the movement of larger fish from the ship channel into shallower areas of the bay. Coefficients for the rest of the year are quite small, and are based primarily with young-of-the-year fish.

Hildebrand and Cable (1930) state that zero- and one-year-old fish are present in shallower waters throughout the winter (larger fish are rarely seen) with the one-year-old fish becoming scarce in harbors and estuaries during long cold snaps. They reported that larger members of the 0 age class also leave shallow waters during cold spells, which coincides with the Mobile Bay data. Gunter (1945), Pearson (1928), and Welsh and Breder (1923) found that spot leave shallow water upon the approach of cold weather.

Hildebrand and Cable (1930) stated that young spot often ascend shallow brackish water ditches during the spring and early summer. Zilberberg (1966) shows that juvenile spot were more abundant in very shallow tidal marsh creeks than in canals and isolated shallow ponds in northwest Florida. He took very few spots over one year old in the marshes at any time of year, and shows abundance of juvenile spot from January to July, with a peak in March. High juvenile abundance in shallow marsh areas from January to March was noted by John Bell (personal communication) for Mobile Bay.

The major portion of the diet of 40-99 mm spot in Lake Pontchartrain consists of zooplankton and unidentified organic material (Darnell, 1958), which might be found most readily in marsh areas. Although he reports an increase in the percentage of organic material and detritus with an increase in size, he attributes this increase to incidental ingestion paralleling the increase in consumption of bottom burrowers. He also states that many of the invertebrate species which were abundant in the food of larger spot appear to be inhabitants of deeper water, indicating that the spot utilizes these areas to a great extent. Dawson (1958) noted that juvenile spot frequent the shallow creeks and marshes in South Carolina, but states that, except for periods of very low temperature, no consistent trends in size or abundance were evident when comparing data from shallow (10-18 feet) and deep (22-30 feet) stations.

The biomass of spot by depths (Figure 9a-f) shows that spots were taken in low abundance throughout most of the year, but distribution was fairly widespread.

The heaviest concentrations in May and June occur in the 7-15 foot depths. These depths are intermediate in temperature between warmer shallow and cooler channel waters. Density of spot is light throughout the bay during July and August (Figure 9b), when temperature gradients remain about the same. Bottom temperatures are somewhat lower throughout the bay in October, with the percentages of spot remaining about the same, except in the shallow areas where it is lower. The concentration is again in moderate depth areas in November and December, except for shallow areas in Bon Secour Bay. By this time, surface waters were cooling rapidly, and had dropped below the temperatures in the ship channel. In January and February, the heavy concentration in the lower ship channel was even more striking than that of the croaker. Approximately 91 percent of the total January and February spot catch of 14.5 kg came from two lower bay ship channel stations. Average bottom temperatures had dropped to 9.3, 9.0, and 11.4°C for shallow, medium, and deep areas, respectively. Figure 9e for March and April shows a dispersal to medium and shallow areas, as the bottom temperature increased rapidly.

Spots utilize very shallow areas as postlarvae and young, but older spots prefer moderate depth areas regardless of temperature, if it is not extreme. Deep areas within the estuary are needed for spots as for croakers for a refuge during cold spells.

SUMMARY

Biological and hydrographic stations were occupied in Mobile Bay from May, 1963 through April, 1964 at 32 locations. Supplemental data on the offshore bottomfish industry enabled the life history of spot and croaker to be followed through three age groups.

Salinity gradients indicate a counter-clockwise circulation in the bay, with major inflow into Bon Secour Bay, and up the east side of Mobile Bay. River drainage flows mainly down the western section of the bay. Little cross-circulation occurs from east to west because of a shallow spoil bank along the western side of the ship channel. A salt wedge extends up the channel at least as far as the northern transect of stations. Salinity ranged from 0.0 o/oo to 34.0 o/oo; bottom temperatures ranged from 5.6^{o}C to 31.0^{o}C. The bottom temperatures in the channel averaged about 2^{o} warmer in winter, and 2^{o}C cooler in summer than in shallower areas. Equalization of bottom temperatures throughout the bay occurred in October and in March-April. Little variation was found between temperatures in 3-6 foot and 7-15 foot depths.

The influx of croaker juveniles indicates that spawning occurs off Mobile Bay from September through March, the peak occurring from September to December. Spawning probably occurs over a wide area, extending a considerable distance offshore, and is not limited to the mouths of passes.

Juvenile croakers, first found inside the bay in October, were spread throughout by November. Growth estimates are low indicating a size of 115 to 120 mm at one year of age. One-year-old fish were taken in steadily declining numbers from May through October, when they moved offshore to spawn. The 0- and I-year-old fish were dominant in the bay, the II age class offshore. Larger 0-age-class fish emigrated in July-August, returning to the estuary in the fall. They also migrated offshore for a limited period during January, probably to escape frigid water temperatures. After spawning, II-age-class fish declined in abundance, and were largely absent from the offshore fishery by the following fall as they approached three years of age.

Croakers, the most abundant fish by both weight and number were at peak abundance in May-June, and October; and at lowest abundance in July-August.

Young of the year croakers show an apparent cline of increasing size with increasing salinity, but this may be an artifact connected with food preference changes as they increase in size.

Croakers were not abundant at low temperatures, but young croakers appeared to be more cold tolerant than older individuals. Apparently, juvenile and one-year-old croakers prefer moderate depth to shoal waters, even if temperatures are equal. In very cold weather, croakers concentrated in the warmer ship channel.

Spots probably spawn from December to at least as late as February. The major portion of the spawning population is offshore during the spawning period; most of the spawning probably takes place in depths in excess of 15 fathoms (15 miles offshore at Mobile).

Inshore data on the spot were primarily limited to 0-age-class fish. Spot reached an estimated size of 140 mm at the end of their first year, and 200 mm at the age of two. 0-age-class fish entered the bay from January through March. At the age of one, larger individuals migrated offshore in the winter and apparently did not return to the bay, constituting a considerable portion of the offshore fishery. The smaller individuals of that age group migrated offshore during their second year. An offshore division of depth preference was noted, with older fish concentrating in deeper water. Fish over two years of age had largely disappeared from the fishery by the fall after their first spawning. Few fish considered to be over one year old were taken in Mobile Bay during the summer, fall, and winter.

The spot ranked second in abundance by both weight and number, being most abundant in Mobile Bay in May-June, and abundant in November-December. Spot appear to increase in abundance along the northern Gulf of Mexico in a west to east direction.

Postlarval spot disperse into shallows and marsh areas as they enter the bay, but move into shallow open bay waters in the spring. Heaviest concentrations occur in waters of moderate depth along the middle of the bay throughout the summer and fall, although dispersal is wide. Spot approaching one year of age are found almost exclusively in the ship channel and deep area around the mouth of the bay in the coldest portion of the year, with those that remain in the bay through the winter moving into shallower waters in the spring.

Little evidence was found to indicate any relationship between size of spot and salinity. Spots were taken at all salinity ranges but were most abundant at higher salinities.

Although spots were taken at a temperature of 6.3^{o}C, abundance drops off sharply below 9.0^{o}C. The preference of spot for deeper, warmer areas in periods of frigid shallow water temperatures is shown by the presence of 91 percent of the total biomass of Mobile Bay spot in the ship channel in January-February. After young-of-the-year spot leave the marsh areas, they appear to prefer moderate depth areas within the estuary, regardless of temperature, if it is not extreme.

With both croaker and spot, the regressions of length on salinity, temperature, and depth proved of little value because of the interrelationships of the three independent variables.

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MODELS OF OCEANIC MIGRATIONS OF PACIFIC SALMON AND COMMENTS ON GUIDANCE MECHANISMS. *By William F. Royce, Lynwood S. Smith and Allan C. Hartt. U. S. Fish and Wildlife Service, Fishery Bulletin 66, No. 3, p. 441-462. 1968.*

This paper, in the humble opinion of the reviewer, represents a milestone in our understanding of a highly controversial subject, the migration of salmon. In FISH MIGRATION by F. R. Harden Jones (St. Martin's Press, New York, 1968) the author states, ". . . the return of mature salmon from the North Pacific to the coastal waters can be accounted for by drift, by random or systematic search, by orientation to water currents at a rheocline, or by orientation to celestial clues: all appear to fit the facts so far as they are known." In a review (Trans. Amer. Fish. Soc. 98(3):545) I refuted the adequacy of any of the above four methods of orientation to explain salmon migration during their oceanic travels. The theory now advanced by Dr. Royce and his colleagues, after painstaking analysis of the known oceanic distributional patterns and movements of three populations of Pacific salmon, is the most reasonable explanation that has been offered.

It is pointed out that Pacific salmons occupy almost all of the North Pacific north of about lat. 41°N. in winter or lat. 48° N. in summer, and all of Bering Sea south of the ice pack. They occur mostly in the upper 10 m --- far from any contact with the bottom. Although, during the final stages of migration, guidance may be governed by imprinting, they point out that the long oceanic migration to distant waters and return has to be performed with no possibility of learning from a parent and with a poor chance of spawning successfully to perpetuate the race if it becomes lost or departs from the required time schedule. The navigational system must depend entirely on an inherited series of responses to stimuli.

The pink salmon of the southeastern Alaska-British Columbia coast reach the ocean proper during July, August, and September. They do not scatter at random, but turn northward along the coast in a band extending about 20 miles offshore. They continue around the northern periphery of the Gulf of Alaska and southwestward past Kodiak Island. Here the band widens and the procession is joined by young pink salmon from Prince William Sound, Cook Inlet, and Kodiak Island. They demonstrated that they are moving in one direction and faster than the current by fishing a large purse seine facing in opposite directions. Similarity of movement of other species was shown by simultaneous capture of juvenile sockeye, coho, and chinook salmons, and steelhead trout. They estimated during 1964 a daily northward migration past any point off southeastern Alaska of 750,000 juvenile pink salmon.

The southeastern Alaska-British Columbia juvenile pinks leave the coastal belt east of long. 160° W., and scatter southward between midautumn and midwinter. Here they enter the eastward-flowing Subarctic Current continuing on a counterclockwise route back toward their original point of departure. Since the distance from the northern Gulf to the center of their winter distribution is at least 1000 miles, which appears to be covered in about 90 days, their indicated rate of travel is 10 miles per day.

Since sockeye salmon (unlike pinks) usually remain one or more additional years at sea their oceanic migrations are more complex. Many may make a huge circular migration two or more times before they mature and return toward their spawning area. The distances traveled may vary from 3000 miles in 12 to 15 months for southeastern Alaska-British Columbia pinks to annual distances of over 2000 miles for chum and sockeye salmon spending 2 to 3 years at sea.

Contrary to once-held views, particular stocks of salmon do not tend to school as a group in the ocean. Salmon of different species, age groups and sizes are taken on single sets of gear, except when close to a destination for mature salmon, when one stock may predominate.

It is noteworthy that juveniles appear to move about 10 miles per day and maturing salmon average 25 to 30 miles per day, occasionally averaging 45 miles per day over long distances. These far exceed the speeds of the currents they follow. These migrations terminate on a very consistent schedule. It appears to be common for a single interbreeding population to keep a schedule that varies from the average by only a few days. This is less variable than the seasonal change in the weather. Thus if the timing of salmon migrations were governed by certain critical temperatures in the waters through which they are distributed, the arrival date would vary by about two weeks around a mean.

In postulating a guidance mechanism the authors refer to the common direction of travel following the North Pacific currents, and the fact that they do not drift, but actively swim with the current. Water movement is dismissed as the clue since the salmon have no stationary reference point, neither are they concentrated along the interfaces between currents where turbulence might be detected. Sun orientation is quite unlikely because of very consistent cloud cover, night migration, and the prevailing storms and fogs of the North Pacific.

The authors review literature on the detection by several species of fishes of very slight differences in electrical potentials. Such slight electrical potentials occur in sea water moving through the earth's magnetic field, and, furthermore, they are polarized across the current with a reverse polarity in an opposite direction. Voltage is nil when moving with or against the current. The authors state that the necessary experiments on the electric sensitivity of adult salmon have not been performed. However, they point out that ocean currents produce electric potentials in a range which some species of fish are known to be able to detect. This excellent paper should be read by all who are interested in fish migration.

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INFORMATION FOR CONTRIBUTORS

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